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ABSTRACT

This book, which can be used only in the Air Force ROTC program, elucidates ideas about air navigation techniques. The book is divided into two main parts. The first part describes the earth's surface and different components of navigation. A chapter on charts provides ideas about different kinds of charts and a variety of symbols used in preparing them. The second part of the book describes various techniques used in navigation. The areas described in this section include preflight preparation, dead reckoning, navigation instruments, radio and electronic navigation, radio language and communication procedures. A description of the variety of information available to pilots is informative. (PS)

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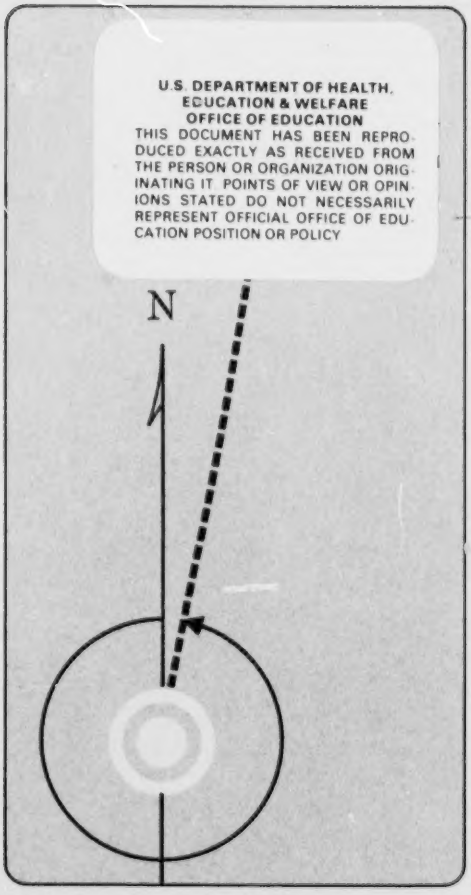


Aerospace Education

II

# AIR NAVIGATION

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*Air Force Junior ROTC*
*Air University/Maxwell Air Force Base, Alabama*

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AEROSPACE EDUCATION II

# Air Navigation

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and

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Academic Publications Division
3825th Support Group (Academic)

AIR FORCE JUNIOR ROTC
AIR UNIVERSITY
MAXWELL AIR FORCE BASE, ALABAMA

1969

This publication has been reviewed and approved by competent personnel of the preparing command in accordance with current directives on doctrine, policy, essentiality, propriety, and quality.

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This book will not be offered for sale. It is for use only in the Air Force ROTC program.

# Preface

WHEN THE TOPIC of navigation is mentioned, many of us envision a mathematical genius slaving over charts, computers, slide rules, and a varied assortment of instruments in an attempt to figure out where he is and where he is going. You may be thinking about the same thing right now.

Hopefully, this text will prove to you that these kind of preconceived ideas about navigation are largely exaggerated and unfounded. We will investigate the wide world of air navigation in an attempt to become better acquainted with the procedures and techniques of navigation. We will not study the use of complex computers and highly technical uses of navigation tools. But we will look at the basic tools used by most pilots and navigators.

We will be introduced to the four primary methods of navigation. We will also discover what is involved in navigating an aircraft from one point to another. The use of charts and maps, types of projections, and measurement of distances will be examined. We will look at the role of the Federal Government in aviation, our primary point of focus being on navigational aids. The Appendices should be referred to frequently to aid in understanding this topic.

It is not the purpose of this unit to make expert air navigators out of you, but rather to introduce you to the world of air navigation. If by the time you finish this text you feel slightly more interested in navigation, then our mission will have been accomplished. We feel that air navigation is not the dry and computer-like world it is usually considered to be. Navigation is alive, exciting, and an active part of the modern aerospace world.

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**Part One**

# Earth's Surface, Mapping and Measurement

THIS PART of the text contains valuable information on constructing map projections and measuring distance and direction on these projections. Chapter 1 explains several of the major problems encountered in projecting the earth's shape onto flat maps. For example, we will look at the task of measuring distance and direction by using a system of parallels and meridians.

In Chapter 2 we will get a closer look at the types of projections. Although we will concentrate on the Lambert projection, we will also become acquainted with Mercator, gnomonic, and stereographic projections. All of these charts have certain specific characteristics that make them suitable for various types of navigation.

The third chapter introduces the several types of aeronautical charts used in air navigation. Chapter 3 also contains a description and explanation of the different aeronautical symbols that are employed on navigation charts.

In general, this part of the text is important because it introduces the idea of projections and aeronautical charts, the primary tools of good navigation. This information is essential to an understanding of navigation techniques, which we will cover in Part II.

*Chapter* 1

# The Earth and Projection

**THIS CHAPTER introduces the methods used by navigators to determine position, direction, and distance. In addition, a discussion of the concept of time is included to show the difficulties that may arise in establishing exact time. This is followed by a consideration of how the difficulties are resolved. The chapter points out some of the basic problems encountered in making projections of the earth. When you have studied this chapter, you should be able to: (1) explain the process by which map projections of the earth are made; (2) define Greenwich Mean Time (GMT) and its relationship to zone time; and (3) describe the methods of determining direction, distance, and position on a projection.**

MOST of today's aircraft flights take place in the atmosphere of the earth. This atmosphere presents many problems to the pilot. When the skies are overcast, a pilot may never see the ground during a flight except at takeoff and landing. Clouds, dust storms, fog, torrential rain, and snow are a few of the many phenomena that may obscure the earth's surface from the pilot.

Even without the presence of a natural obstruction, the earth's surface is difficult to perceive. Distortion is created by altitude and light. Pilots need more than sight and a keen sense of direction to reach their destination.

Maps of the surface of the earth are primary tools in air navigation. To become familiar with the principles of navigation, we must remember a few facts about the earth's surface.

## FACTORS IN NAVIGATION

We first see that the earth is a sphere spinning about on an imaginary line called an axis. At the ends of this axis are the poles. Although the earth is not truly a sphere, it is considered spherical for navigational purposes.

The first step in learning about navigation is to become acquainted with position, direction, and distance. Knowledge of these three factors is necessary for successful navigation. In this chapter, therefore, we will examine the procedures used in producing map projections and the methods of determining position, direction, and distance.

### Position

Position is determined by reference to coordinates in a grid system. A grid system is a network of uniformly-spaced horizontal and perpendicular lines necessary to pinpoint a specific location. Without this grid system, all idea of position would be lost.

Consider yourself a resident of Johnstown, and your city streets as a grid system. A visitor to your town stops and asks you to direct him to the nearest service station. You give him instructions which, if followed correctly, will take him to his desired destination.

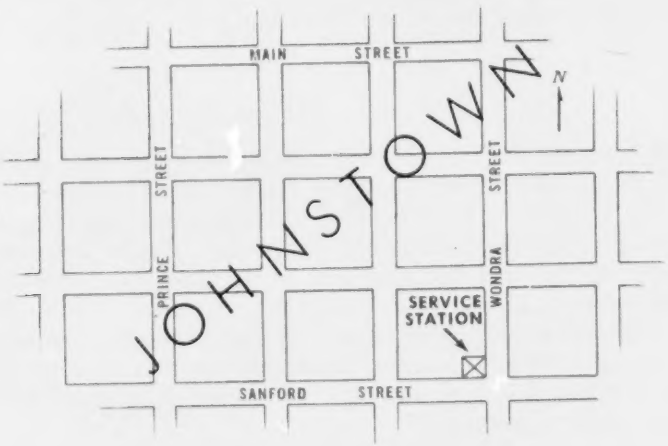


Figure 1. Johnstown street grid.

The station is at the corner of Wondra and Sanford Streets. All the visitor has to do now is follow one of the streets until he arrives at the intersection of the two streets.

Your directions might have been, "Go three blocks south of Main and three blocks east of Prince." These two references are the coordinates of the service station. This second location is just as definite as the first. Both locations have established a specific position for the service station on the map in Figure 1.

Just as the streets of your town serve as reference lines, a system of imaginary lines serves to locate positions on charts and maps. The Equator is an imaginary line drawn around the Earth halfway between the North and South Poles. Other lines drawn parallel to the Equator are called *parallels of latitude*, or more simply, parallels.

Lines which run from the North Pole to the South Pole are called *meridians*, or *lines of longitude*. These lines of longitude are perpendicular to the Equator. The Prime Meridian is that meridian that passes through Greenwich, England. It is used as a reference line for other meridians, much as the Equator serves as a reference line for parallels.

By this system of parallels and meridians, one can easily locate any position on a chart. The position may be north or south of the Equator or east or west of the Prime Meridian. Latitude is always stated first. For example, Miami Beach, Florida, is located on a map at 25° 17′ N latitude, 80° 07′ W longitude.*

## Time

While we are on the topic of latitude and longitude, we should mention the system of keeping time that is used in air navigation.

The earth makes a complete rotation of 360° during a full day of 24 hours. We could therefore divide the Equator into 24 hours instead of 360°, each hour representing 15° of longitude. We have seen that longitude is expressed in degrees, minutes, and seconds of *arc*. It is also possible to express longitude in hours, minutes, and seconds of *time*. If we use the Prime Meridian as our starting point, we can find the location of any point of longitude by expressing it in hours east or west of Greenwich. For example, a point that is at 60° longitude may be expressed as four hours west of Greenwich.

* The symbol "′" stands for minutes of angular measure. Sixty minutes equals one degree (1°) of arc.

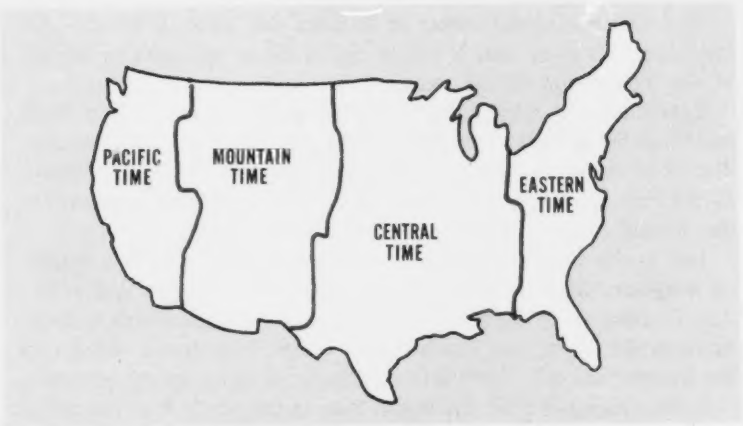


Figure 2. Standard time zones.

ZONE TIME.—Before the establishment of zone time in 1883, every city and town had its own time. As you may well imagine, this situation caused much hardship and left people in a constant state of confusion. Once time zones were established, less confusion occurred.

Each time zone is 15° of longitude (1 hour of angular measure) in width and the first zone centers on the Prime Meridian. However, irregularities have crept into the system because some towns have decided to keep the time of some large city farther west or east. Further confusion entered the picture when "Daylight Saving Time" was introduced. This set the clocks in the affected area one hour ahead.

In Figure 2 we can see that the United States has four standard time zones. The time in any given zone is one hour earlier than in an adjacent eastern zone and one hour later than in an adjacent western zone. The Time Zone Chart of the World, published by the Oceanographic Office of the U.S. Navy Department, shows the standard time zones which divide practically all of the world.

Pilots sometimes become confused in reporting their estimated time of arrival (ETA) because they cannot remember whether they have to add or subtract an hour. Most pilots use one of two methods to give the correct time. First, some pilots give their ETA according to the time their watch has. If their watch is set to central standard time, then they note that when giving their ETA to the tower. For

example, a pilot's ETA is radioed in as 1630 central standard time. The tower personnel then know what time and according to what time zone the pilot expects to arrive. They can make any changes necessary to make the time correct for their specific zone.

GREENWICH MEAN TIME.—The second method, Greenwich Mean Time, avoids the necessity of changing from one zone to another. Greenwich Mean Time (GMT) is the time of day at any given moment at Greenwich, England. If GMT is employed and a pilot requests clarification, he will be given the local standard time. For example, we request clarification of the time and receive the following: 1745 Greenwich, 1245 Eastern. Greenwich time is often noted on communications and teletype reports as "Z". It is therefore often called "Zulu" time, in accordance with the international phonetic alphabet (Appendix A).

The following table should be helpful in converting from standard time to Greenwich Mean Time.

| *To Convert From:* | *To Greenwich Mean Time* |
|---|---|
| Eastern Standard | Add 5 hours |
| Central Standard | Add 6 hours |
| Mountain Standard | Add 7 hours |
| Pacific Standard | Add 8 hours |

Daylight saving time is never used for aviation purposes. To convert from GMT during daylight saving time, add one hour to the tabulated values shown above for GMT.

### Direction

When flying over a long, unfamiliar course, a system is needed to express direction. A direction from any point to any other point is always given in degrees reading clockwise from North. On a compass, North is considered either 0° or 360°; East, 090°; South, 180°; and West, 270°. The compass rose, illustrated in Figure 3, has been developed as an aid to navigation by graphically portraying direction.

The path over the earth that an airplane must fly to reach its destination is called the *course*. True course is the direction of the course measured from true north. To determine true course, we measure the angle between the course line and the meridian midway between departure point and destination. This meridian is called the *mid-meridian*. The angle obtained in this measurement gives us the

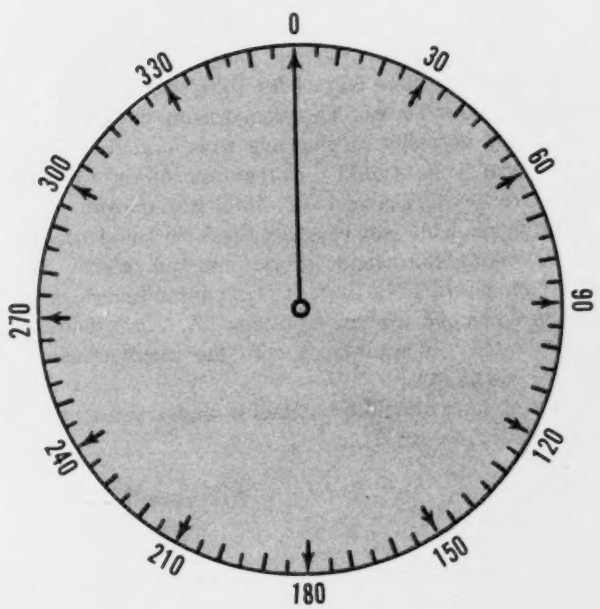


Figure 3. Compass rose.

average true course for the total distance of our trip. In Figure 4 we have placed our protractor along the course line and have measured the angle.

To plot a true course over the shortest distance between two points, a line drawn on a sphere must be arced to follow the earth's curvature. Great circle and rhumb line direction are two types of direction on a sphere.

GREAT CIRCLE.—A great circle is a line drawn around the earth, dividing the earth into equal halves. The imaginary center of all great circle routes is the center of the earth. If you could take a knife and cut through the surface of the earth, through the center of the earth, and through the other side, making two equal hemispheres, the edges of the hemispheres would be great circles. If New York were located along the edge, then the edge could be considered a great circle route between New York and any other points along the edge.

RHUMB LINE.—A line which makes the same angle with each meridian is called a rhumb line. An aircraft holding a constant true heading would be flying a rhumb line. Flying this sort of path results in a greater distance traveled, but it is easier to steer. If continued, a rhumb line spirals toward the poles in a constant true direction but never reaches them.

Between two points on the earth, the great circle is shorter than the rhumb line, but the difference is negligible for short distances (except in high latitudes) or if the line approximates a meridian or the Equator.

## Distance

Distance is the third of the important three aspects of navigation. Land distances are customarily expressed in feet or statute miles. A statute mile is 5,280 feet. In air navigation, *nautical* miles are more commonly used than statute miles. A nautical mile is approximately 6080 feet, or approximately 1.15 statute miles. Whatever system is used, a navigator must be certain that the measurement is the same: either statute or nautical miles. A mixture of the two could result in a miscalculation of enough magnitude to produce a serious situation. For example, a pilot who used statute miles to figure the amount of fuel required for a particular flight, but nautical miles to figure the distance, could err so seriously that he would run out of fuel.

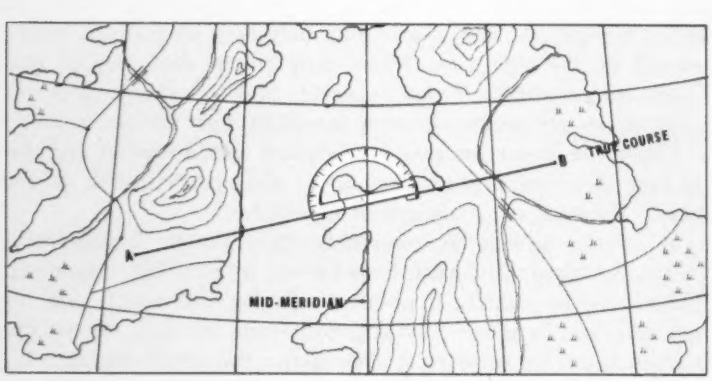


Figure 4. Measuring true course.

Nautical miles can be easily converted to statute miles and vice versa. To obtain statute miles from nautical miles, *multiply* the nautical miles by the conversion factor of 1.15. To obtain nautical miles from statute miles, *divide* the statute miles by 1.15.

As previously stated, nautical miles are more commonly used in air navigation than statute miles. The primary reason for this is that one degree of latitude is equal to 60 nautical miles. By dividing it into minutes of latitude (60 minutes to a degree) one minute of latitude equals one nautical mile. Through the use of the nautical mile system, the navigator has a convenient scale to use between each parallel of latitude on all charts.

## PROJECTIONS

The next area we are going to investigate is projections. A projection is a system of parallels and meridians representing the earth's surface. This study will involve maps and charts and the part they play in the art of navigation. Various types of projections will be studied and the many problems involved in production and usage will be discussed. A general description of the projections will be given, explaining characteristics, distortion, production, and use.

### Maps and Charts

A map is basically a diagram representing part or all of the earth. If a map is specially designed for use in navigation, it is usually called a *chart*. At first, charts were only used by mariners as they set out on the high seas. These early charts were only of water areas and coastlines. Today, however, with the advent of the aircraft, charts are produced which show both land and sea areas.

Charts are important aids to navigation because pilots use them to keep on course and to measure the distance to specific destinations. They are the roadmaps of the skies.

A traveler driving his automobile from Boston, Massachusetts, to San Francisco, California, finds his way by referring to roadmaps. Towns can be identified, positions can be determined, and time schedules can be planned. Navigation charts are used for the same purposes, but the traveling is done above the earth's surface.

Because the earth is spherical, it is impossible to draw a flat map of the world which truly represents the earth's surface. Distortion

would make the chart inaccurate. Although a globe is the only true representation of the earth, a usable globe would be too large and cumbersome to keep in the small, cramped cockpit of an aircraft. For example, using a common chart scale of 1:1,000,000, the globe would have a circumference of over 120 feet.

DISTORTION.—Shape, size, and scale have to be represented on a chart without *distortion.* This is an impossible task to accomplish. As an example of this problem, cut a rubber ball in half and try to flatten it out on a table. It cannot be done without the ball having wrinkles or cracks. Likewise, the surface of the earth cannot be represented on a flat chart without some distortion.

Charts of small areas can be relatively free of distortion, but not entirely. Take a small piece of the rubber ball, try to flatten it out. Notice that the results with a smaller piece of the ball are better than with a larger piece. However, there is still some distortion. A chart may be drawn so that the distortion will be held to a minimum for the specific purpose of that chart. To use that chart for a purpose other than that for which it was made, however, would make the chart impractical.

PRODUCTION.—The production of maps and charts is an important part of the overall study of navigation. Any point on earth may be located on a map or chart by using the previously mentioned system of coordinates. A chart can be produced by representing the geographic features of the earth on a framework of parallels and meridians, which become, in turn, the map coordinates. This framework formed by the parallels and meridians is called a *graticule.* By referring to the meridians and parallels, the land and water features may be placed in their respective positions on the graticule.

The construction of the graticule is an important step in the production of charts. General characteristics, appearance, and scale are all determined by the form of the graticule. The process of building the graticule is called *projection.*

To better understand the graticule of a chart, imagine a light bulb placed in the center of a transparent sphere. On the sphere are opaque meridians and parallels. The light from the bulb casts shadows upon the plane of any surface held next to the sphere. These shadows are what actually form the pattern of the graticule.

The picture created by the shadows cast from within the sphere is similar to the original features of the globe, but there is some

distortion. As explained before, the smaller the area to be taken from the globe, the smaller the amount of distortion.

We have examined various problems related to making projections. Hopefully, we now have a better idea of what is involved in production of aeronautical charts. Chapter 2 will give us a look at the types of projections used in air navigation.

## REVIEW QUESTIONS

1. **What is a primary source of information for air navigation?**
2. **Describe the earth's axis.**
3. **Name the imaginary line drawn around the earth halfway between the north and south poles.**
4. **In which directions do meridians run?**
5. **What is another term for lines which run in the same directions?**
6. **What are parallels and what is their purpose?**
7. **Is there another term which can be used in place of parallels?**
8. **What are the two types of courses drawn on a sphere?**
9. **Define the term "great circle."**
10. **How many feet are in a nautical mile? Compare it to a statute mile.**
11. **Explain the term "projection."**

## THINGS TO DO

1. From an aeronautical chart, list the coordinates (latitude and longitude) of 15 to 20 of the major cities around the world.
2. On a world map mark the Greenwich Mean Time (GMT) at every 30° of longitude.
3. List the zone time and the GMT for the following cities: New York, Atlanta, Los Angeles, Denver, San Antonio, Chicago, Boise, Memphis, Seattle, Anchorage, El Paso, St. Louis, Montgomery, New Orleans, and Las Vegas.
4. Using local times, describe an imaginary trip you took by commercial jet (600 miles per hour) from Berlin, Germany, to Paris, France, New York City, Chicago, Denver, and San Francisco. Assume that you land at each city, but take off immediately. Compute the flying time and give the local time that you would arrive at each stop.

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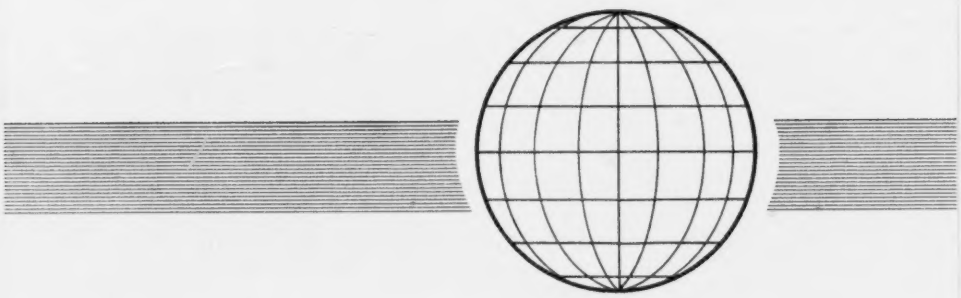

*Chapter* 2

# Types of Projections

**THIS CHAPTER examines the three most commonly used types of projections: conical, cylindrical, and azimuthal. Variations and refinements within the types are examined. Such variations include Lambert, Mercator, gnomonic, and stereographic projections. When you have studied this chapter, you should be able to: (1) tell the differences among the four most commonly used projections; and (2) explain why certain projections are used for specific purposes.**

ALL PROJECTIONS overlap to some degree, but it is impossible to classify them into one general category. In practice, the pilot or navigator of today has several classifications which he uses more than others. This chapter will explain these classifications and illustrate the differences in projections.

## COMMON PROJECTION TYPES

The three most commonly used projections are conical, cylindrical, and azimuthal. The Lambert conformal conic projection is the most extensively used conic projection, while the Mercator is the most widely used cylindrical projection. Azimuthal projections, such as the gnomonic and stereographic, are used for special purposes.

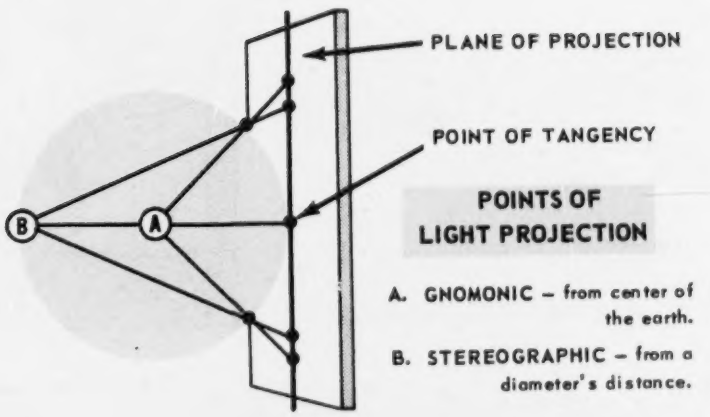


Figure 5. Azimuthal projections.

Air navigation requires plotting and measuring by the pilot or navigator and the Lambert conformal and Mercator cylindrical projections are used more than any other forms for these purposes. The accuracy of these two charts makes plotting, measuring, and map reading easier and more exact.

### Azimuthal Projections

An azimuthal projection is one on which points on the earth have been transferred directly to a plane tangent to the earth. According to the location of the plane, the point of tangency, and the origin of the light, various geometric projections result. Figure 5 shows the light source locations used in the preparation of azimuthal projections. If the origin of the projecting rays is the center of the earth, a *gnomonic* projection results. If the projection is the point on the surface of the earth opposite the point of tangency of the plane, a *stereographic* projection results. Although there are other types of azimuthal projections, we will discuss only the two most often used, the gnomonic and stereographic. Each of these types may be further classified, such as a polar stereographic or equatorial stereographic.

GNOMONIC.—The gnomonic is one of the oldest of all projections, believed to have been constructed by the Greek philosopher Thales

about 550 B.C. The Greeks believed that the stars were attached to the inner surface of a great sphere in the sky. Apparently the gnomonic projection was devised in an effort to project these stars onto an imaginary plane beyond this great sphere. This idea is seen in the construction of the projection when it is observed that the meridians and parallels are projected onto a tangent plane. Then the center of the earth is the point of projection.

Perhaps this is better seen in Figure 6. A plane is held tangent to the earth, the point of tangency being the equator, and the meridians and parallels are projected upon it. The center of the earth is the point of projection and is in the plane of every projected great circle. Every great circle is seen as a straight line on the projection. It is only on the gnomonic that this is possible.

Because the Equator and meridians are great circles, they appear as straight lines on the projection. Parallels, not being great circles, always appear as curved lines.

Distances are difficult to measure on a gnomonic chart and areas are not correctly represented. Shapes and angles are also distorted. Because of the many possible forms of the graticule, plotting of points is difficult. One saving point of the gnomonic chart is that every straight line is a great circle. As previously noted, the shortest distance between two points on the earth is a great circle. Therefore, the principal use of gnomonic charts is in the plotting of great circle routes.

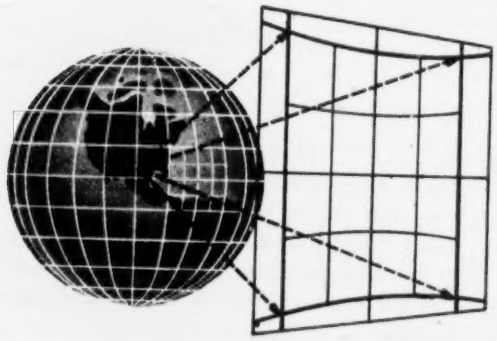

Figure 6. Plane tangent at the Equator.

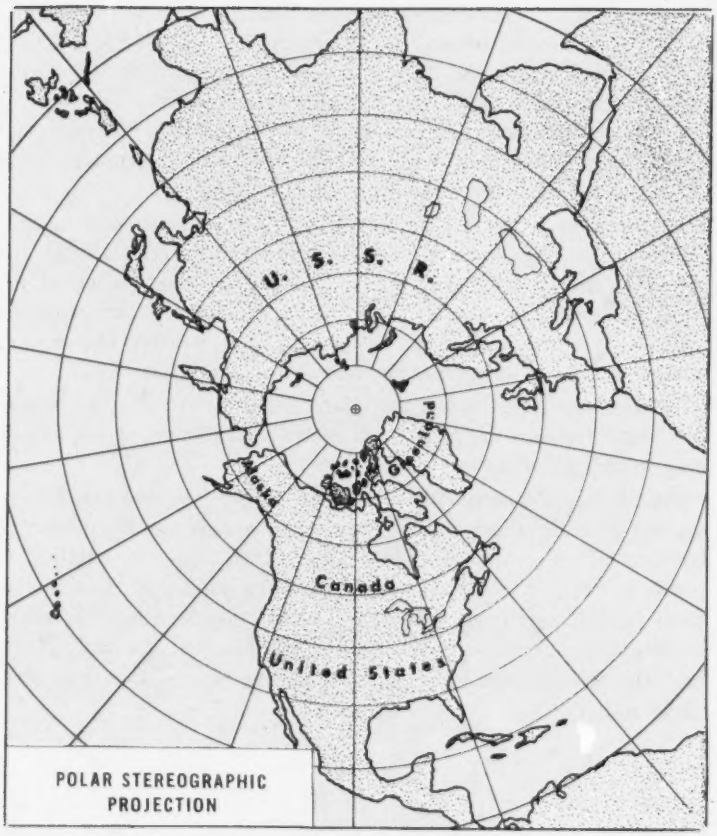


Figure 7. Polar stereographic projection.

STEREOGRAPHIC.—The stereographic projection, credited to the Greek astronomer Hipparchus, was devised in the second century B.C. The polar stereographic is a good example of a true azimuthal projection. It is produced on a plane that is tangent to the earth at the pole. Some stereographic projections are made with other points of tangency, but these are of little use for air navigation.

The pole appears at the center of the projection and meridians appear as straight lines radiating from the pole. As seen in Figure 7, parallels appear as concentric circles about the pole. As their

distance from the pole increases, so does their distance apart on the projection.

A stereographic chart may include a whole hemisphere, but those charts used in navigation extend only 20° or 30° from the pole. While there are other types of stereographic charts, characteristics given here are those of a polar stereographic navigational chart.

Within the limits of this chart, the scale changes little, remaining constant in all directions from any point.

Since the meridians appear as radii of the circles representing the parallels, the meridians and parallels intersect to form 90° angles on the chart, just as on the earth. All other angles are also correctly shown.

Another characteristic of the chart is that a circle on the earth always appears as a circle on the chart. Meridians, which are great circles, appear as straight lines radiating from the center of the projection. Any great circle passing through the center of the chart appears as a straight line; other great circles are slightly curved. On a polar stereographic chart, a straight line approximates a great circle, and for practical purposes, is considered to be a great circle. Rhumb lines appear as curved lines.

### Cylindrical Projections

As previously stated, the Mercator is the only cylindrical projection that is widely used in air navigation. Introduced in 1569 by Gerhard Kramer, also known as Mercator, this projection is used primarily for marine navigation and occasionally for long distance

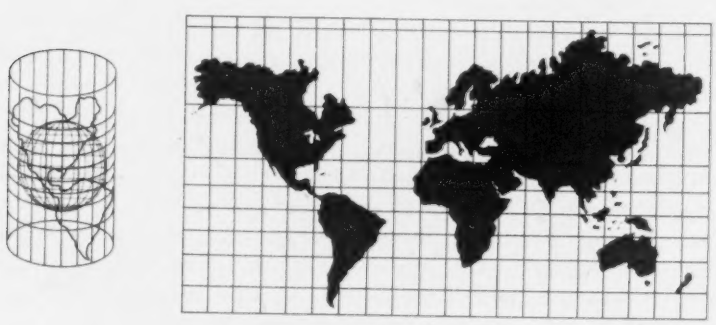

Figure 8. Mercator projection.

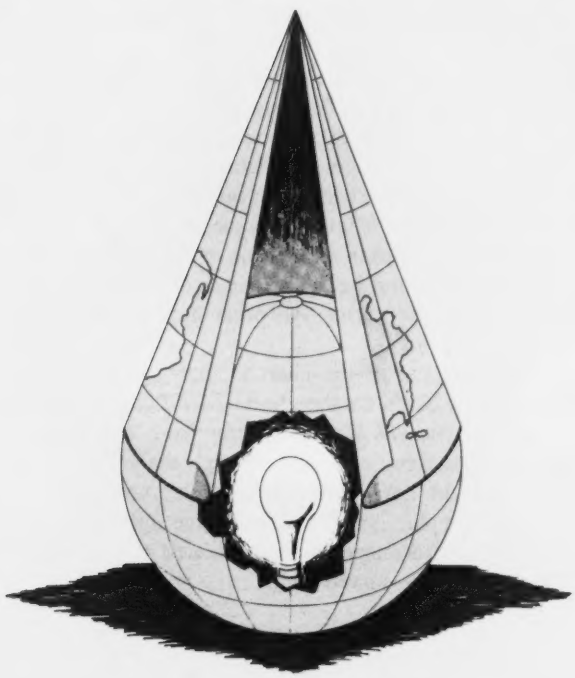

Figure 9. Lightbulb principle of Lambert conic projection.

air navigation. Correctly known as the Mercator conformal projection, it is commonly referred to as "the Mercator" because it is the best known of his projections.

In making the projection, in Figure 8, the earth is projected upon a piece of rectangular paper which then can be shaped around the sphere of the globe. When this rectangular piece of paper is wrapped around the earth, a cylinder is formed. The cylinder touches the globe at the Equator. In this manner the meridians and parallels appear as straight lines. This projection is only completely accurate at the Equator. Land areas north and south of the Equator are distorted. Shapes are correctly shown within small areas, while distortion appears over large areas. Great circles will appear as curved lines and Rhumb lines will be straight lines.

When this projection was first used, ships traveled a single course for perhaps a full day. Under these conditions this chart had a

distinct advantage for marine navigation because the entire day's voyage could be plotted as a straight line. Today, however, as an airplane rarely travels the same course for more than an hour at a time, the Mercator projection is unsatisfactory.

In most instances of air navigation, the Lambert has replaced the Mercator projection.

### Conic Projections

A conic projection is created by placing a cone tangent to a globe at a parallel. The axis of the globe coincides with that of the cone. To better understand, imagine a light bulb placed in the center of a globe as illustrated in Figure 9. The bulb is the origin of the projection and the meridians and parallels are projected onto the cone. The meridians are shown as straight lines which meet at the poles. Parallels are arcs of circles whose centers lie along the axis of the earth.

THE LAMBERT.—The Lambert conformal conic projection, referred to as the Lambert projection, is one of the most commonly used charts today. Because it affords maximum accuracy in direction and distance, the Allied forces of World War II adopted the Lambert as one of their primary aeronautical charts.

As seen in the illustration in Figure 10, the Lambert projection resembles the earth as it appears on a globe. Meridians point to the poles, and parallels are approximately equally spaced. The earth's

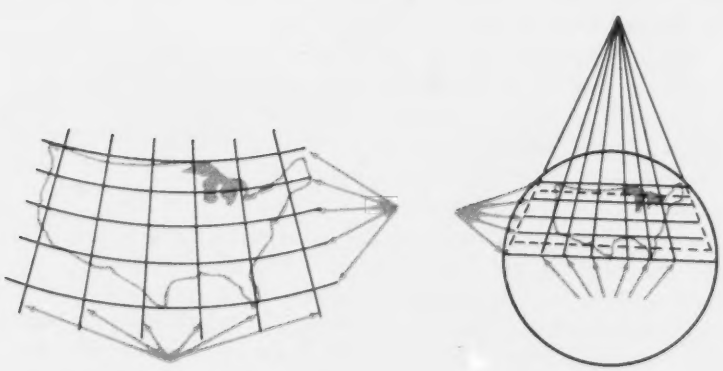

Figure 10. The more accurate Lambert representation of the Earth.

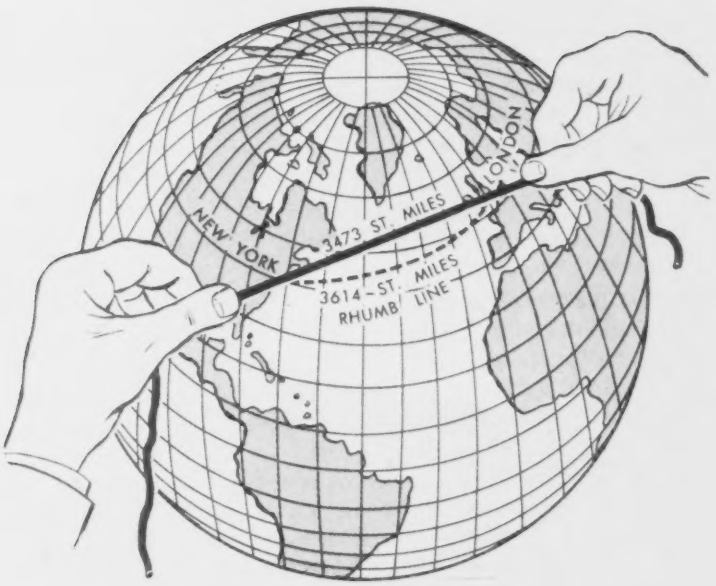


Figure 11. Great circle route.

representation is very accurate. If a straight line is drawn between two points on a Lambert projection, the line will closely approximate a great circle. Then, as in Figure 11, this straight line will be the shortest distance between two points.

Although this straight line approximates a great circle, it is not actually a great circle route. For practical purposes, the difference is not great enough to force the usage of a great circle route. Generally, the Lambert projection is the best chart to use if measurements of distance or direction are to be made. Direction must be measured at the mid-meridian, however.

We have examined three types of projections. The conic, cylindric, and azimuthal are the three most commonly used projections. Because most air navigation deals with these three types, any student of navigation should have a working knowledge of them. In this study, we have only briefly examined them to see what they are, how they are built, and what they are used for. We would have to explore much further to become accomplished pilots or navigators.

The next chapter will explain the differences between the various charts that are used in air navigation. Several different charts are used by pilots to plan their flights. Each chart has a specific purpose and so each contains different information. Every pilot must be able to accurately read aeronautical charts. Charts are his roadmaps in the sky and without them he would not be able to plan and make a flight of significant distance.

## REVIEW QUESTIONS

1. **List and explain three types of projections used in air navigation.**
2. **What is the advantage of using a Lambert conic conformal chart in air navigation?**
3. **Which type of projection is used primarily for marine navigation?**
4. **Name and briefly describe two types of azimuthal projections.**
5. **Illustrate a Mercator projection graphically.**
6. **Compare advantages and disadvantages of a polar gnomonic, a Lambert, and a Mercator.**

## THINGS TO DO

1. Draw an aeronautical chart, using appropriate symbols, of the area within 5 miles radius of your school.
2. Using two different types of projections, preferably a Lambert conformal and a gnomonic or a Mercator, measure the true course and distance between two points at least 1000 miles apart. Describe the differences between the two courses. Consider differences of distance, difficulties in measuring course and distance and how far apart the courses were at the point of greatest separation.
3. Using plastic materials, construct a plastic sphere with a light bulb in the center as shown in Figure 9. Draw the major continents of the world on the sphere and show how the various types of projections are made.

## SUGGESTIONS FOR FURTHER READING

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TOWER, MERRILL E. *Flight Facts for Private Pilots.* Los Angeles: Aero Publishers, Inc., 1960.

U.S. Air Force. *AFM 51-40, Air Navigation.* Vol 1. Washington, D.C.: Department of the Air Force, 1968.

*Chapter* 3

# Charts

**THIS CHAPTER examines the different charts used by air navigators. In this study of Sectional, Local, Planning, World Aeronautical, Jet, and Operational charts the aeronautical and topographical symbols used on navigation charts are introduced. When you have studied this chapter, you should be able to: (1) explain the different uses of each chart; (2) describe the specific benefits derived from the use of certain charts; and (3) find aeronautical information on the charts.**

MANY TYPES of charts are used in air navigation. These aeronautical charts are differentiated by their functional uses, and the information they contain determines their usage. The name of the chart is a reasonable indication of its intended use. An example is the Jet Navigation Chart. It has properties that make it adaptable for the speed, altitude, and instrumentation of the jet aircraft. In this chapter we will examine the differences and uses of various aeronautical charts.

## CHART DIFFERENCES

In addition to differences in the specific type of information they contain, charts also vary in amount of information. Certain charts are used specifically for planning long-range flights. This type of chart would not have the great detail that a Local chart would. Local charts are of specific areas and contain much detail.

Charts used in air navigation are published by the United States Coast and Geodetic Survey. The Coast and Geodetic Survey is a

component of the Environmental Science Services Administration* (ESSA). It is charged with the topographic and hydrographic survey of the coast and inland areas of the United States.

### ESSA's Charts

A list of ESSA's most widely used charts includes (1) the Sectional, (2) the Local, (3) the Planning, (4) the World Aeronautical, and (5) the Jet Navigation. As you can deduce from their names, these charts are designed for different and specific uses.

*Sectional charts* are intended for use by private pilots and are used in pilotage planning. Identified by names of principal cities or significant geographical features, there are 87 sectional charts that cover the entire United States. Their scale of about 8 statute miles per inch allows for great detail.

*Local charts,* with a scale of about 4 miles per inch, show more detailed topography than any other chart. This chart is designed for use in congested areas when flying by visual flight rules. These charts are also identified by names of cities, such as Denver Local.

*Planning charts* are used for planning long flights. They have a scale of about 80 miles per inch and are helpful in selecting key points which then may be located on larger scale maps.

*The World Aeronautical Chart (WAC)* was once one of the most commonly used charts. In a day of high speed aircraft, however, these charts have certain drawbacks. They are to a scale of about 16 miles per inch and this limitation forces the charts to omit many topographical features. Moreover, the problem with a WAC in high-speed flight is that an aircraft can fly across a whole map in less than an hour. Finally, WAC's are almost useless over the ocean since some have virtually nothing but water shown on them. Today WAC's are used primarily by pilots flying local areas. The charts are still used to a diminishing degree, but they are being replaced by Operational Navigation Charts (ONC).

*Jet Navigation Charts* are used for long-range navigation at high speeds and high altitudes. Four of these charts cover the entire nation. Airline pilots and military personnel flying jet aircraft use these charts when flying across the United States.

An important point to remember is that all pilots should check the publication dates of each chart that is used. The dates are usu-

* Other components of ESSA are the Environmental Data Service, Weather Bureau, the Institutes for Environmental Research, and the National Environmental Satellite Center.

ally found in the lower right corner of the charts. Changes made may include information regarding such subjects as new radio frequencies, obstructions, temporary closing of airways, and other similar information.

## CHART SYMBOLS

The information contained in the symbols on all charts is of great importance to the pilot. A glance at the symbols will inform the pilot what type of facilities are provided at each airport. Another glance will tell him what types of terrain he is passing over, what size towns are along the route, and what cultural features are below. All of these facts are contained in the region of symbols on each aeronautical chart.

### Types of Symbols

Information placed on aeronautical charts is divided into two areas: aeronautical and topographical symbols. Aeronautical symbols, as seen in Figure 12, contain (1) aerodrome information, (2) aeronautical lights, (3) radio facilities, and (4) miscellaneous aeronautical symbols.

The topographical symbols shown in Figure 13, include (1) cultural features, (2) relief, and (3) water areas. All of these symbols are contained on the back of most charts. Almost all charts use the same symbol but even on charts that use different symbols, the symbols are so similar that relationships are easily made.

AERONAUTICAL INFORMATION.—Aeronautical information, such as restricted areas, is printed in magenta and blue colors on U.S. Coast and Geodetic Survey sectional charts. Different classes of airports are distinguished by different symbols. The elevation is given next to the symbol of each airport. Light beacons are shown with their code signals. Locations of radio stations, with call letters and frequency and the position of the radio beam, are also shown. All airways, danger areas, and other important features are clearly marked. It must be noted, however, that charts used by USAF pilots and navigators are produced by the Aeronautical Chart and Information Center and do not contain all of the above information.

TOPOGRAPHICAL SYMBOLS.—Many types of topographical symbols are used on aeronautical charts. These symbols are also of the utmost importance to the air navigator.

# AERONAUTICAL SYMBOLS

Figure 12.

## AERODROMES

AERODROMES WITH FACILITIES — LAND / WATER

Civil

Joint civil and military

Military

Aerodromes with hard-surfaced runways at least 1500 feet long

Civil Military

HELIPORT

(H) (selected)

AERODROMES WITH EMERGENCY OR NO FACILITIES — LAND / WATER

Landing area

Anchorage

Aerodromes with hard-surfaced runways at least 1500 feet long

### AERODROME DATA

ATIS ---------- Automatic Terminal Information Service

2427 ------ Elevation in feet

L ---------- Lighting { L-Lighting available Sunset to Sunrise; *L-Lighting available Sunset to Sunrise on prior request; (L)-Lighting available part of night only

S ---------- Normally sheltered take-off area

48 ---------- Length of longest runway in hundreds of feet

Control Tower Frequencies { LF/MF shown first (transmits only), followed in order by primary VHF local control and primary military VHF/UHF (transmits and receives), and non-standard guarding. Standard guarding 122.5 mc not shown. Note: for details see panel titled "Assigned Radio Frequencies for Air Navigation."

LAND

WOODSTOCK
ATIS 115.9
2427 L 48 U
Airport of entry
GCA ILS DF
278 119.5 126.2
257.8 122.7R

WATER

NAS NORFOLK
00 L S 250
3053

ALBERT 1750 - 36 U ---------- Aerodrome name may be omitted when same as nearest town name. ---------- 1750 - 36 U

When facility or information is lacking, the respective character is omitted or replaced by a dash.

U: indicates aeronautical advisory station licensed to operate on 123.0 mc at airport with control tower or FSS, on 122.8 mc at airport without control tower or FSS

## AIR NAVIGATION LIGHTS

Rotating light

Rotating light (with flashing code)

Rotating light (with course lights) 27

Flashing light Fl

Flashing light (with code) Fl

Marine light

Lightship

Marine alternating lights are red and white unless otherwise indicated. Marine lights are white unless colors are stated.

F-fixed FL-flashing Occ-occulting Alt-alternating Gp-group R-red W-white G-green B-blue (u) unwatched Sec-sector sec-second Mo-morse code E Int-equal interval.

## RADIO FACILITIES

Facilities have voice unless indicated "No voice".
All radio facilities are printed in blue with the exception of certain LF/MF facilities such as tower frequencies, radio ranges and radiobeacons, which are printed in magenta.

Radio range (without voice) (two letter identification assigned Radio range when associated with VOR) — SPRAGUEVILLE 371 SPR No voice

Marine radiobeacon (all are without voice) — RBn LOS ANGELES 302 H + 01 & ev 6m

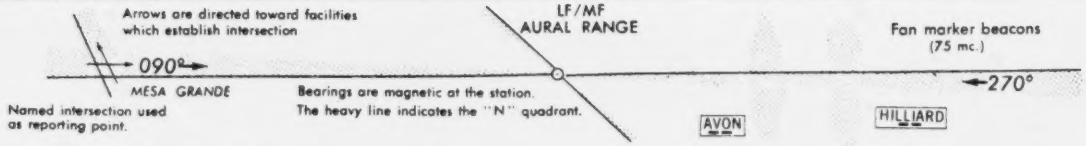
Radio communication station — CS FORT WORTH 365

Radio broadcasting station — BS KGAF 1580

Radiobeacon, nondirectional (homing) (with voice) — WICHITA FALLS 287 WWA

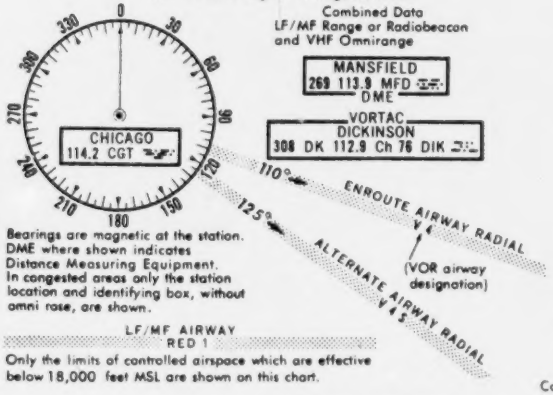
Localizer (shown when component of airway system) — LCZR or LOCALIZER 109.5 I BED

Outer marker radiobeacon (shown when component of airway system) — LOM or LOM 359 EW




## VHF OMNI-DIRECTIONAL RADIO RANGE (VOR) COLLOCATED VOR AND TACAN (VORTAC)

Omni rose is aligned to magnetic north.




Bearings are magnetic at the station.
DME where shown indicates Distance Measuring Equipment.
In congested areas only the station location and identifying box, without omni rose, are shown.

LF/MF AIRWAY
RED 1

Only the limits of controlled airspace which are effective below 18,000 feet MSL are shown on this chart.

## CONTROLLED AIRSPACE LEGEND

CZ = Control Zone TA = Transition Area

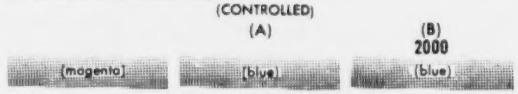
The limits of controlled airspace are shown by tint bands (vignette) and are color-coded in blue and magenta to enable the pilot to quickly determine the level at which controlled airspace begins.

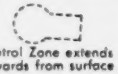
All values are referenced to the earth's surface unless indicated as MSL (mean sea level).

Magenta vignette-controlled airspace begins at 700' above the earth's surface.

Blue vignette (A) controlled airspace begins at 1200' above the earth's surface; (B) if other than 1200' the value is shown.

The dark edge of the vignette indicates the limit, and the vanishing edge the direction of controlled airspace.



Control Zone extends upwards from surface

(UNCONTROLLED)
Uncontrolled airspace within the United States extends up to 14,500 feet. At and above this altitude all airspace is within the Continental Control Area.

## MISCELLANEOUS

Prominent Transmission line ----T----T----
or T-line crossing ----T----T CAUTION

Rotating light (on top of high structure) 1504

Obstruction, 2150 UC
(numerals indicate elevation above sea level of top)
(larger figures used for emphasis) 2550
(UC: Under Construction, position and elevation unverified)

Isogonic line 8°E
(values for 1965)

Mooring mast

Abandoned airport (Abandoned airport)

Parachute Jumping Area

## AIRSPACE RESERVATIONS

Airspace Reservations effective below 18,000 MSL are numbered, and are indicated on the chart as follows:

Prohibited Area
P-78 C6P9
Prior approval required before flying into any Prohibited or Restricted Area

Restricted, Warning or Danger Area
R-2802 W-20 C5D20

Caution or Jet Training Area
C-54 WEBB-REESE

214 / 10-20-67

**Figure 13. Topographical symbols.**

*The cultural features* division of topographical symbols indicates man-made features, such as towns, roads, and railroads. Towns and cities are represented according to size by several methods. While a circle or square denotes a small town, it does not represent the shape and scale of the town. The town can be recognized from the air only by its relative position to other features. A pilot must learn by experience just how large a town is when seen from the air. After some experience, a pilot can then recognize the size of a town by the map symbol.

Railroads and highways are usually helpful because they are conspicuous from the air. Although roads are often omitted because of congestion, railroads are always represented on charts used today. Because railroads are more permanent than roads, they are likely to be more accurately represented. Charts may or may not show bridges, but the pilot knows that where a road or railroad crosses a river, there must be a bridge or a tunnel.

Other cultural features, such as race tracks, oil wells, tank storage depots, and ranger stations have special symbols. There are no specific symbols for other features, such as smoke stacks, water towers, and monuments. These features usually are marked by a special symbol and have some brief descriptive note attached.

*Relief* is the elevation of the land surface; that is, the difference in elevation of low and high areas. Elevations are important in air navigation because they are good landmarks and, if high enough, they present a hazard to flight. As far as is practicable, land elevations are given on aeronautical charts. Spot elevations and highest peaks are usually marked. In addition, relief is also further represented by means of contours.

A contour is a line connecting points of the same elevation. The shore line of the sea might be thought of as the 0-foot contour. Every point on this contour is at an elevation of zero feet above sea level. On a steep slope, the contour lines would be close together; on a gentle slope they would be farther apart.

Relief is further shown on sectional maps by a system of gradient coloring. The area between −276 feet and sea level is colored dark green; between sea level and 1,000 feet light green; between 1,000 and 2,000 feet light green diagonal lines; areas between successively higher elevations are marked in different shades of brown from light to dark. The darker colored mountain peaks stand out conspicuously, even to one not experienced in contour reading.

Bodies of water have proven to be helpful in air navigation.

They are valuable because they are relatively permanent and it is easy to see them by day and often at night. Coast lines may be accurately shown, even though inland areas may be little explored and poorly mapped. Usually, water is shown in blue, but this does not mean that all bodies of water look blue from the air.

We have looked as the various methods used to represent features of the earth on aeronautical charts. Endless hours have gone into the careful preparation of aeronautical charts. Experts make every possible attempt to assist pilots in reading flight charts.

Aeronautical charts are of great importance to the pilot. No experienced pilot would think of flying his craft anywhere without first consulting his charts.

## REVIEW QUESTIONS

1. **How are aeronautical charts differentiated?**
2. **What government organization publishes aeronautical charts of the United States?**
3. **List four types of aeronautical charts and explain how they are used.**
4. **Explain the differences between aeronautical and topographical symbols used on charts.**
5. **Why are aeronautical charts important when planning air flights?**
6. **How are elevation differences shown on a relief map?**

## THINGS TO DO

1. There are many maps and charts, old and new, used for both marine and air navigation. Make a collection of as many of these as you can find and put on a display for your class or school.
2. Plan a flight of at least 150-200 miles between two cities and describe to the class how you would use landmarks as checkpoints to keep your airplane on course. Assume that you will be in a light plane flying at a low altitude.
3. Choose four or five teams in your class and give each team a sectional or some other identical charts. Using a list of 20 topographical and aeronautical symbols prepared by your instructor, have a contest to find out which team can find and circle the complete list of symbols first.

## SUGGESTIONS FOR FURTHER READING

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**Part Two**

# Navigation Techniques

THIS PART of this volume contains several interesting aspects of air navigation. First of all, we will explore the different navigation techniques that are used by today's pilots.

Pilotage, dead reckoning, celestial and radio navigation are the primary forms of navigation. While each form may be used independently, pilots and navigators often use varying mixes of navigation techniques. For example, general aviation pilots, who normally fly within local areas, primarily employ radio and pilotage. Commerical pilots, who must navigate over large, often dangerous areas, must rely upon all available types of navigation. This is true also for military pilots and navigators who are often responsible for highspeed aircraft, capable of altitudes and speeds unknown to general and commerical aviation. These pilots and navigators must depend upon radio, radar, and celestial navigation. They also, however, often use both pilotage and dead reckoning for certain low-level missions.

Simply stated, then, different types of aviation—general, commercial, or military—use varying combinations of navigation techniques. The type of navigation used is determined by the area of the flight,

the speed and altitude of the aircraft, and the weather conditions. When one type of navigation cannot be used, another type must be available. With this continuous interchange of navigation techniques, aircraft pilots and navigators are able to fly from place to place, despite such physical limitations as rocky terrain, large expanses of water, and inclement weather.

Again, let's reiterate a point previously made. We are not trying to make you proficient navigators, but are merely presenting enough information so that you may obtain some basic knowledge and a better understanding of the broad area of air navigation. It is hoped that you will obtain some insight into the skill required for navigating and enjoy learning something of the methods and techniques involved.

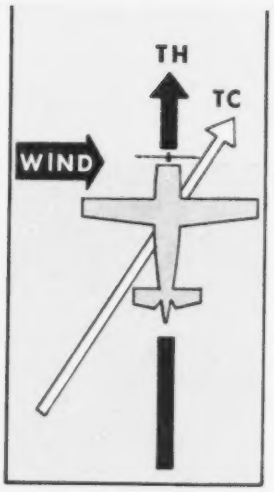
Contained in this unit are chapters on the use of flight instruments and weather information available to pilots. The chapter dealing with flight instruments concerns only the four major instruments. Those that are used most often are the clock, magnetic compass, airspeed indicator, and the altimeter.

We will examine the weather information organization and see what types of data are available. Weather information is of the utmost importance to pilots planning any type of flight. It is imperative that pilots know what type of weather lies along the flight path.

A considerable amount of material is contained in this section. All of the information is of importance to aircraft pilots. We hope that when you have finished studying these chapters, you will have a better understanding of air navigation and its processes.

*Chapter* 4

# Pilotage




**THIS CHAPTER introduces the first navigation technique. Pilotage navigation is examined to provide a firm base upon which to build other navigation techniques. Chart preparation and flight planning are presented to show what work is involved in making a safe flight. In addition, the two important concepts of variation and deviation are added to assist in planning a flight. When you have studied this chapter, you should be able to: (1) describe the pilotage method of navigation; (2) prepare aeronautical charts for flights; (3) fill out flight plans; and (4) compensate for variation and deviation in navigation computations.**

PILOTAGE is the first method of navigation that a pilot learns. Of the four methods of navigation, pilotage is the simplest to use and the easiest to learn. It is used in every type of navigation, if just to locate and identify the correct airport at the end of a flight. We will look at the other types of navigation later, but first let us examine navigation by landmark observation so we can learn the various procedures it involves.

Pilotage has been described as the process of locating landmarks on the ground and matching them with a chart of the territory over which the aircraft is flying. With the aid of his aeronautical charts, the pilot in Figure 14 can locate his position by referring to prominent landmarks observed from the air. By locating these features

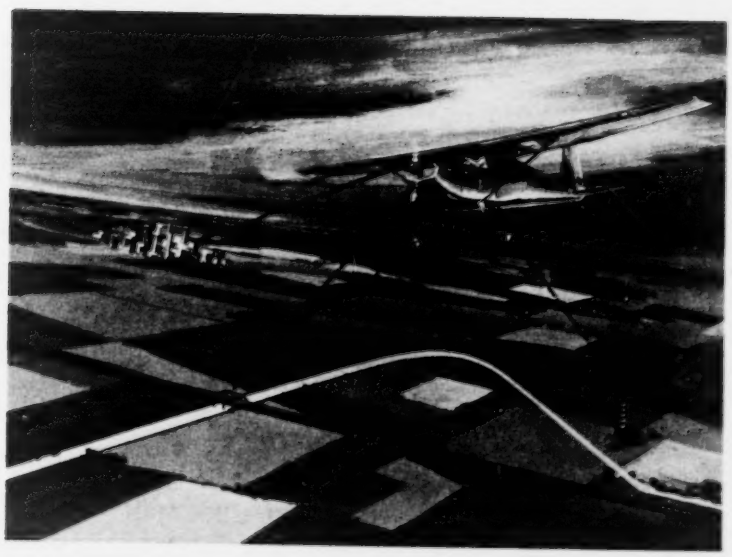


Figure 14. Pilotage.

on his chart, the pilot maintains his desired course and assures that he remains headed in his desired direction. Commonly used landmarks are towns and cities, railroads, highways, lakes, rivers, mountains, bridges, towers, airports, and power lines. These symbols may be seen in the section on charts.*

Pilotage is primarily used for flying light or slow aircraft by visual flight rules (VFR) over distances up to several hundred miles. Radio aids or computers are not necessary for pilotage navigation. Visual contact with the ground is the guiding means of pilotage.

Pilotage is an unsatisfactory means of navigation when flights are over water or areas of few distinguishing landmarks, or when weather prevents visual contact with the ground. At these times, a pilot must employ dead reckoning or instrument navigation, or a combination of both.

## PREFLIGHT PREPARATION

A pilot must take several actions in preparation for every flight. Not only must he visually check the condition of his airplane, but

* See symbols shown on page 27.

he must obtain all necessary flight information and prepare his aeronautical charts. Careful pre-flight preparation by the pilot is mandatory for safeguarding against possible danger. We will examine two highly important pre-flight preparations that all pilots complete prior to takeoff: chart preparation and the making of a flight plan.

### Preparation of Charts

Most pilots employ standard procedures when planning pilotage flights and while in actual flight. Sectional charts are recommended for most lightplane navigation. Charts of smaller scale are too difficult to use. Charts showing greater detail are better for pilotage navigation.

In the preparation of the charts, a true course line is drawn from the point of departure to the point of destination. This course line is then divided into segments of 10 or more miles, depending upon the speed and range of the airplane. By dividing the course line into segments, a quick glance at the chart, as shown in Figure 15, will tell the pilot how far he has yet to travel. The mileage is already marked off for him. This will save valuable time because the pilot does not have to search for mileage figures.

Landmarks along the route are then designated as checkpoints. These checkpoints are used to check heading and to determine groundspeed of the craft. Prominent features of the terrain, such as railroads, rivers, and major highways, called checkpoints, are

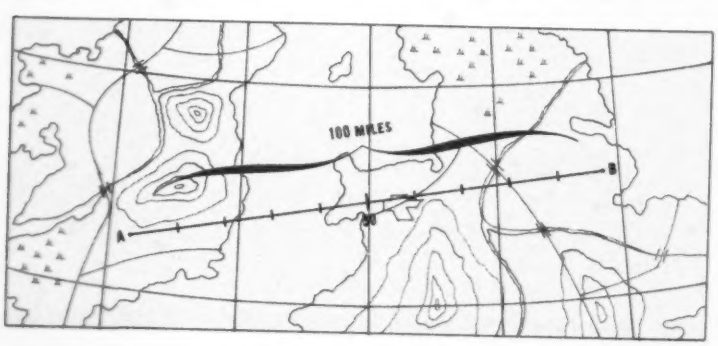



Figure 15. Dividing a course line.

selected along either side of the course and at the destination. Checkpoints serve as easily recognizable guides along the route, enabling the pilot to locate quickly his position and desired direction.

Compass heading is then established and noted. This is the compass reading that should be followed in order to reach the proposed destination.

Because pilotage is most commonly used in flying light aircraft, we will prepare our aeronautical charts for lightplane navigation. All Air Force pilots are first instructed in flight methods and navigation techniques in light aircraft. A prospective pilot completes his initial training in light planes before he flies larger planes and jet aircraft.

Before we begin, we might drop two hints for easier navigation. In the section on aeronautical charts, we noted that all aeronautical charts are updated at specified lengths of time. A pilot must ascertain that he has the most up to date chart available. He should always check the date of the chart, usually found in the lower right corner. Too many pilots have exhausted valuable time and fuel looking for checkpoints that no longer existed. Pilots should always use the latest edition of every aeronautical chart.

Another point to remember is that a pilot should always have adjoining charts. Very often a pilot's route will come near the edge of a chart. If he does not have adjoining charts and he is blown off course, or desires to leave his original course, he may become stranded without a chart of the land below.

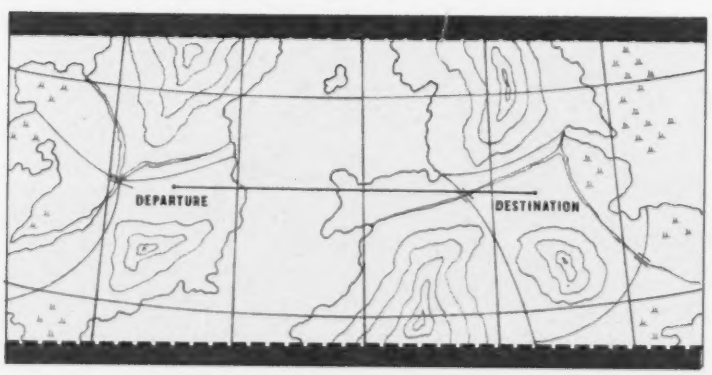



Figure 16. Folded map with only area of flight showing.

When two or more charts are used, they can be joined by using clear cellulose tape. Most other materials, such as glue and paste, distort the surface of the charts.

After the charts are joined, the pilot draws a straight line from departure to destination. He then folds the charts so that only the area of the flight is showing, as in Figure 16. This provides rapid identification of landmarks and position because irrelevant landmarks are folded out of sight.

Next the pilot evaluates the straight-line course drawn between departure and destination points. Will this direct route be safe or would a more roundabout course be better? Are there large mountain ranges, large bodies of water, or other hazardous obstructions along the route? Are there easily recognized landmarks? Are airports located within easy flight of the course?

These are just a few of the many questions raised when evaluating a flight route. All questions must be answered before takeoff. A safe pilot never allows chance to be part of his flight. He knows what he is doing at all times. A sign frequently seen in base operations at U.S. Air Force bases reads, "You can't plan a safe flight in a hurry."

## MAKING THE FLIGHT

Once off the ground, new tasks require the attention of the pilot. Although pilotage is the least complicated of the four types of navigation, there is much to do while flying by visual contact. Let's take a quick look at these procedures.

Immediately after takeoff, the time is noted over the airport and the plane is headed toward the first checkpoint. At this checkpoint, the predetermined compass heading is taken up. Between this checkpoint and the next, the drift of the aircraft is checked. A correct heading, allowing for wind drift, is then taken up that will lead to the destination.

Several checks of elapsed time between checkpoints gives the pilot constant readings of groundspeed. At all times, the pilot maintains a continuous scrutiny of the course by using predetermined checkpoints and *brackets*—the crossing and recrossing of the radio directional beam to insure the proper heading.

Visual contact flying requires that the pilot stay alert. He must be observant and careful. Pilotage navigation is fun and practical, but one must remain prepared to use other forms of navigation when necessary.

### Flight Plans

When planning a flight, all available information should be considered. The Federal Aviation Administration provides the pilot with its *Airmen's Information Manual* (AIM) which contains several aids to navigation. Among these aids are Notices to Airmen (NOTAMs), which contain airport changes and airway information, a complete airport directory, weather services, and other information about aids and services provided for convenience and safety. NOTAM's are kept current by teletype message and are posted for pilot reference.

In preparation for a flight, if a flight is expected to extend for more than an hour, the pilot reviews current weather reports and forecasts, winds aloft reports, and pilot reports. The pilot should personally visit the nearest weather station or Flight Service Station (FSS) to consult these reports and forecasts.

Flight Service Stations, identified for radio-telephone purposes by the name of the city in which they are located (Clearwater Radio,

FEDERAL AVIATION AGENCY

**FLIGHT PLAN**

Form Approved. Budget Bureau No. 04-R073.

| 1. Type of Flight Plan | 2. Aircraft Identification | 3. Aircraft Type | 4. Estimated True Air Speed | 5. Departure Time: Proposed | 5. Departure Time: Actual |
|---|---|---|---|---|---|
| ☒ IFR ☐ VFR ☐ DVFR | N925H | PI85 Beechcraft | 140 Knots | 1010 Z | 1030 Z |

| 6. Initial Cruising Altitude | 7. Point of Departure | 8. Route of Flight |
|---|---|---|
| 8,000 | IOL | V212N |

| 9. Destination (Airport & City) | 10. Altitude Changes En Route | 11. Estimated Time En Route: Hours | 11. Estimated Time En Route: Minutes | 12. Fuel on Board: Hours | 12. Fuel on Board: Minutes |
|---|---|---|---|---|---|
| ELM | NONE | 1 | 10 | 04 | 00 |

| 13. Alternate Airport | 14. Remarks |
|---|---|
| BGM | VFR CONDITIONS AT STROUDSBURG AND WILKES BARRE IFR @ IOL AND BGM |

| 15. Pilot's Name | 16. Pilot's Address or Aircraft Home Base | 17. No. of Persons Aboard |
|---|---|---|
| John H. Jones | 1234 Rainwater Avenue, Anyplace, State | 4 |

| 18. Color of Aircraft | 19. Flight Watch Stations (FAA Use) |
|---|---|
| Red/Gray | VHF 115.9 117.3 |

SEE REVERSE SIDE — CLOSE FLIGHT PLAN UPON ARRIVAL — Form FAA-399 (3-60)

Figure 17. Flight plan.

for example), are air traffic communication stations maintained by the FAA. Located at major airports, they provide thorough coverage along the controlled air travel lanes called airways. Teletype lines connect all stations with each other and with weather stations across the Nation.

The FAA requires all pilots to file *flight plans* for every flight that uses instrument flight rules (IFR). This flight plan, shown in Figure 17, is filled out on a standard form provided by the FAA. The pilot must fill in all the required information before takeoff and file the plan with the departure airport.

Information on the flight plan must contain pilot and aircraft identification, place and time of departure, proposed cruising altitude, expected airspeed, proposed route and destination, and the estimated time of arrival (ETA). Information also specifies an alternate airport for use in an emergency.

Although flight plans are not required for flights using just VFR, it is wise to file a flight plan. If the aircraft contains a 2-way radio, the pilot is authorized to use the FAA "Flight Following Service." This service will track the aircraft during its entire flight until the destination is reached. The pilot must file a flight plan to obtain this service.

Once the flight plan has been cleared and approved, all communication stations (FSS) along the proposed route are notified of the flight. FSS personnel will then brief the pilot on the latest weather conditions, forecasts, notices, and stations to contact.

After takeoff, the pilot must report his takeoff time to the FSS. He then must contact each check station along the route as he passes over them and he will be given the latest information relative to his flight. Upon arrival at his destination, the pilot must notify the nearest FSS and report his arrival. The station will then close his flight plan, knowing that he has successfully completed the flight.

Now that we have examined the pre-flight and flight procedures, let's put them to work. We are going flying and you are the pilot-navigator.

We have mentioned several things about pilotage navigation that need further explanation. First, we must plot the true course. This is done by measuring the number of degrees the course will lie, counting clockwise from north. The best way to do this is to use the meridian line that is approximately half way between the de-

parture and destination points. This measurement can be done with a plotter or a protractor and will be explained later in the text.

Several factors arise that will prevent you from flying exactly over the precise course that you have established. Therefore, a distinction is made between the true course (the intended direction of the flight) and the *track* (actual flight over the ground).

### Variation

Another step toward better navigation is the application of variation to the true course. Aircraft use magnetic compasses that refer all directions to magnetic north rather than true north. True north is the reference for all measurements on the chart. Magnetic and true north do not coincide and this fact creates a difference between the two readings. This difference is called variation and, depending whether the direction of magnetic north lies west or east of true north, it is either a westerly or an easterly variation. All aeronautical charts show the amount of variation at any locality by lines of equal variation called *isogonic lines*. Where magnetic north and true north are the same, there is no variation. This line of no variation is called the *agonic line*. Magnetic variation is westerly in the Northeastern section of the United States and easterly in the rest of the

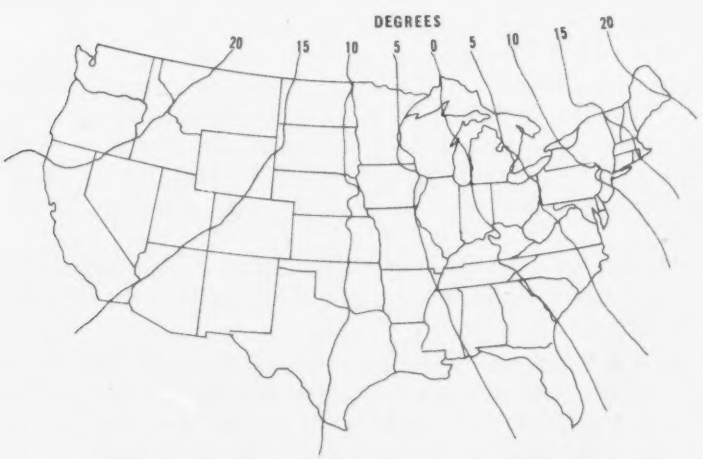



Figure 18. Magnetic meridians.

Nation. Illustrated in Figure 18, the agonic line (line of no variation) extends approximately from Lake Michigan through the Appalachian Mountains to just off the east coast of Florida.

A conflict arises when we measure courses from a chart with reference to true north and then try to fly this course by using reference to a magnetic compass. We are forced to apply the variation to the true course to find the magnetic course. A basic rule of navigation, one that cannot be forgotten, is that to convert true course to magnetic course, *always add westerly variation, subtract easterly variation.*

As examples of determining magnetic course, examine the following problems:

1. You are going to fly from Greenstown to Stimson on a course of 040°. Your chart shows the nearest variation to be 10° east. You now apply the rule of subtracting easterly variation and determine your magnetic course to be 40° − 10° = 30°.

2. Shrimpton to Tridear. True course of 310°, variation 05° west, magnetic course is 315°. (Remember to add westerly variation.)

3. Aaron to Barker. True course 135°, variation 07° east, magnetic course is _____?

To summarize: To convert true course to magnetic course, observe the variation shown by the nearest isogonic line. Add, if variation is west; subtract, if variation is east. Navigators frequently remember this rule by saying, "East is least, west is best."

### Deviation

Compass needles are frequently deflected from their normal readings. This change in accuracy creates a problem for the pilot trying to follow a magnetic course. Magnetic influences from within the plane, such as lights, tools, engines, electrical circuits, and magnetized parts, cause the needle to fluctuate. This difference in compass reading, called *deviation,* has to be compensated for while flying. Each plane has a different deviation and so cards are devised that indicate the amount of deviation for each aircraft. Pilots then make the necessary compensation for deviation. These deviation cards, placed near the compass, show the amount of addition or subtraction necessary for correction of deviation at different head-

COMPASS

SWUNG: _____ BY: _____

| TO FLY | STEER | TO FLY | STEER |
|---|---|---|---|
| N | 0 | | 180 |
| 30 | 28 | 210 | 212 |
| 60 | 58 | 240 | 242 |
| 90 | 87 | 270 | 275 |
| 120 | 118 | 300 | 304 |
| 150 | 148 | 330 | 333 |
| | | | |
| | | | |
| | | | |
| | | | |
| | | | |
| | | | |

Figure 19. Compass deviation card.

ings. As shown in Figure 19, most deviation cards are marked in 30° intervals and for corrections that fall between those that are given, mental interpolation is generally accurate.

For example, we want the correction for 200°. The deviation card has a correction of zero for 180°. The correction for 210° is plus 2. We can then assume that the correction for 200° is plus one. Our course is then 201°. Once the magnetic heading has been found and corrected for compass deviation, it is called the *compass heading*. This compass heading will then enable us to fly to our desired destination.

In this unit, we have examined some of the aspects of pilotage navigation. We saw how charts were prepared and used and how a pilot actually prepares for a VFR flight. Flight plans and in-flight procedures were also discussed. We hope that a better understanding of pilotage, and navigation in general, has been obtained from the reading of this chapter.

Air navigation is exciting and not nearly as complicated as many would have us believe. In the next chapter on Dead Reckoning, we will look at yet another method of navigation. This also should prove interesting.

## REVIEW QUESTIONS

1. **Explain the navigational technique called pilotage.**
2. **List five landmarks that would make good identifying points for a pilotage flight.**
3. **Explain what checkpoints are and how they are used.**
4. **What is a major disadvantage of pilotage flying?**
5. **What is the reason for having checkpoints along an intended course?**
6. **Why should a pilot divide his course line into segments?**
7. **How does a pilot go about making up a flight plan?**
8. **What is a major reason for filing a flight plan?**
9. **Why is it important to close out the flight plan?**
10. **Define isogonic lines.**
11. **What is the agonic line?**
12. **Define variation and the rules for its use.**
13. **What is deviation?**

## THINGS TO DO

1. Using an aeronautical chart, plan a flight with at least 10 major changes of direction and describe to the class how you would identify each turning point on the chart using pilotage.
2. Plan a flight of at least 200 miles. Plan your course and ground speed checkpoints as described in your student text booklet.
3. Draw a course line on a Lambert conformal chart, making sure that the course line crosses at least 12 meridians. Measure the course angle at each meridian and explain your findings to the class. Compute the average of all of your readings and compare the results to the course angle measured at the mid-meridian.

## SUGGESTIONS FOR FURTHER READING

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LYON, THOBURN C. *Practical Air Navigation*, 10th ed. Denver: Jeppesen & Co., 1966.

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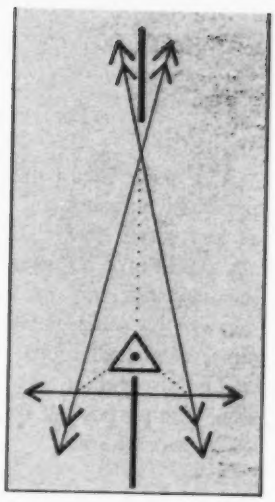
*Chapter* 5



# Dead Reckoning

**THIS CHAPTER is built upon the information contained in the chapter on pilotage. Since dead reckoning is one of the most frequently used methods of navigation, this is an especially important chapter. The six factors necessary for dead reckoning navigation are presented and explained. In addition, the construction and use of a wind triangle is explained. The last two sections of this chapter describe the use of a wind correction angle and how to make certain important flight computations. When you have studied this chapter, you should be able to (1) describe how to fly from place to place by using dead reckoning navigation; (2) construct a wind triangle and apply the values derived from it; (3) determine time in flight; and (4) determine the amount of fuel consumed in flight.**

DEAD RECKONING (DR) is the basic method of navigation. The term can best be understood by examining its probable origin. Mariners of an earlier day deduced their positions at any time by using the distances and directions of motions of their vessels since passing or leaving a known position. Such positions were determined at frequent intervals and were entered in the ship's log book in a column headed by the abbreviation "ded. pos.," for "deducted position." The reckoning necessary to get the information for these entries was known as "ded reckoning." Over the years, through popular usage "ded reckoning" became "dead reckoning."

The major idea behind dead reckoning navigation is to know, by pre-flight planning and in-flight checking, the position of the aircraft at any given time. DR navigation enables the pilot to determine the position of his aircraft and to direct it from place to place. He accomplishes this by measuring or calculating and then keeping account of other navigational factors, such as direction, distance, time, wind, and speed. By using his flight plan, a pilot may glance at his information and determine quickly how the flight is progressing. The purpose of this chapter is to enable the student to perform these procedures.

## ELEMENTS OF DR NAVIGATION

The chapter on pilotage has introduced several aspects of dead reckoning. This section will continue and further explain basic navigational procedures. Unlike pilotage, dead reckoning does not rely entirely upon visual identification of landmarks. However, landmarks are used to verify the accuracy of dead reckoning procedures. Fundamental DR navigation procedures include plotting and measuring, using flight instruments, determining wind direction and velocity, flight planning, and calculating new headings in flight as conditions change.

A pilot uses six basic factors in finding his way by dead reckoning: (1) true airspeed (TAS), which is indicated airspeed corrected for errors caused by air temperature, air density, and instrument inaccuracy; (2) true heading (TH), direction from true north in which the aircraft is headed; (3) wind direction (W), direction from which the wind is blowing; (4) rate of speed or force of wind (wind direction and rate of speed combine to give wind velocity (W/V); (5) groundspeed (GS), speed of aircraft over earth's surface as distinguished from its speed through the atmosphere; and (6) true course (TC), the aircraft's intended path over the earth's surface as distinguished from its heading.

### Wind Triangle

A pilot navigating by dead reckoning can determine where his aircraft should be and where it will be by using the known factors to find the unknown factors. He determines the unknown factors in units of speed (knots or miles per hour) or in terms of degrees

(direction). This determination is accomplished by grouping the six DR factors (three speeds and three directions) into pairs to form three *vectors.*

VECTORS.—Vectors, an important concept in air navigation, are quantities which have both magnitude and direction, for example, a wind of 10 miles per hour (magnitude) blowing from 45° (direction). The three vectors used in dead reckoning navigation are (1) the *wind vector,* composed of wind direction (W) and wind velocity (W/V); (2) the *air vector,* composed of true heading (TH) and true airspeed (TAS); and (3) the *ground vector,* composed of true course (TC) and groundspeed (GS).

In solving navigational problems using DR, each vector is drawn as a line on a graph or chart, or visualized by the pilot on the wind face of a computer as in Figure 20. The wind vector, air vector, and ground vector form the *wind triangle,* also called the wind vector diagram.

WIND DRIFT TRIANGLE.—In using the wind drift triangle, the magnitude and direction of two vectors (lines on a chart) are used to find the values of the unknown vector (line). If the values of four of the six quantities are known, the other two may be deter-

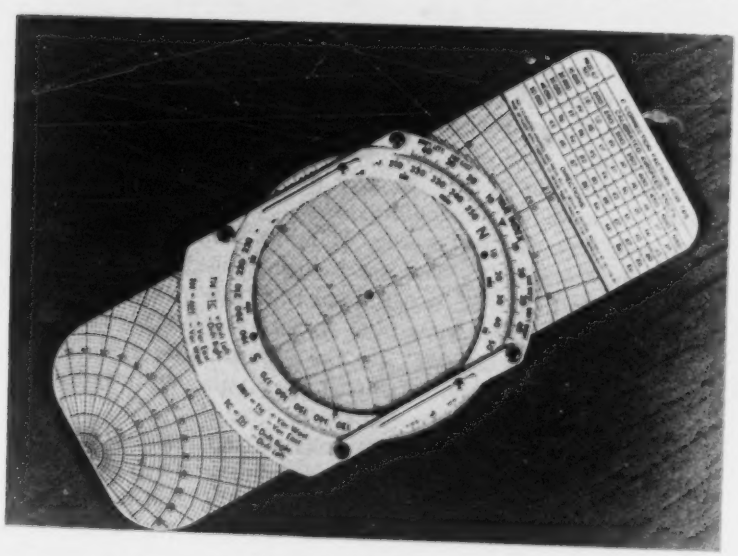


Figure 20. Wind face of computer.

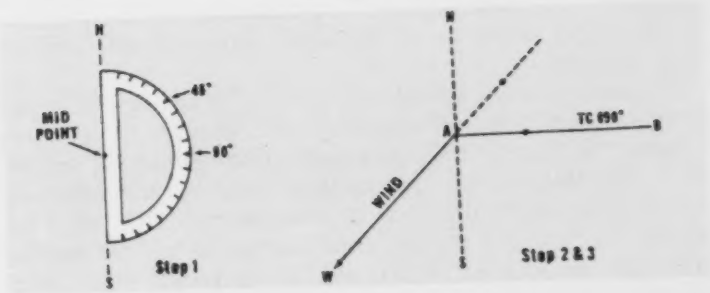



Figure 21. First steps in wind triangle.

mined by completing the wind triangle. For example, if wind, wind velocity, true course, and true airspeed are known, then true heading and groundspeed can be found.

Figures 21, 22, 23 and 24 will help us understand the procedures of diagraming a wind triangle. We want to fly from A to B. We first draw a straight line connecting the two points on our chart. Next we measure its direction with a protractor and determine the true course to be 090°, or due east. The Weather Bureau has reported that the winds at our intended flight altitude are from the northeast (045°) at 35 knots. Since the wind speed has been given in knots, we change the speed to miles per hour, arriving at approximately 40 mph.

In Figure 21 we have drawn a vertical line representing north and south on a sheet of paper. We then place the protractor and make two dots, one at 090° to mark our course direction and one at 045° to mark the wind direction.

We now draw the true course (TC) line from A and extend it through the dot at 090°. This line is then labelled TC 090. Now, still working in Figure 20, we align our ruler with A and the dot of 045°. We draw a wind arrow from A, not toward 045°, but in the direction the wind is blowing. The line is made forty units long to correspond with the wind velocity of forty mph. We identify this line by marking "W" at the end of the line.

In Figure 22 we measure 120 units on the ruler to represent our known airspeed and make a dot on the ruler at this point. The ruler is then placed so that the end is at the "W" and the 120-mile dot intercepts the true course line. We draw the line and label it "AS 120," meaning airspeed 120 mph. At this intersection of

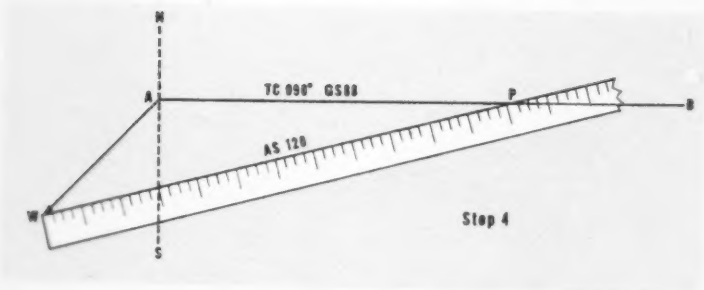



Figure 22. Drawing the wind triangle.

"AS120" and the true course line, we place the point "P," representing the position of the plane at the end of one hour's flight. This completes the diagram and we can now answer our previously unanswered questions.

By placing the ruler along the true course line we can obtain our ground speed by counting the number of units between points "A" and "P." In this case, our GS is 88 mph.

Because wind drift is an important factor in air navigation, it is important that we know how to compensate for it. To find the true heading that we should fly to correct for wind drift, we place our protractor along the north-south line with its center point at the intersection of the airspeed line and the north-south line. The true heading can be read directly from the protractor. In this case, as shown in Figure 23, our true heading is 076°.

DRIFT CORRECTION ANGLE.—Another method of finding the true heading is seen in Figure 23. This method requires that we first

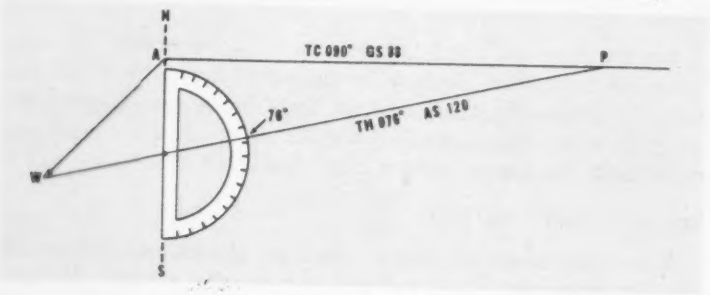



Figure 23. Direct measurement of true heading.

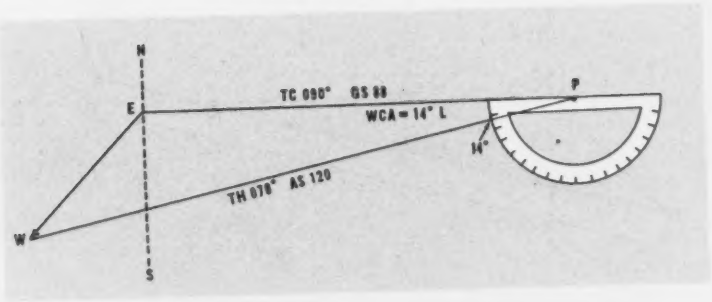



Figure 24. Using the wind correction angle.

find the *drift correction angle (DCA).* The first step is to place the straight edge of our protractor along the true course line. By placing the protractor's center at P, we can read the angle between the true course and the airspeed line. This is the wind correction angle which is then applied to the true course to obtain the true heading. If the wind blows from the right, the angle will be added; if from the left, it will be subtracted. In our example in Figure 24, the DCA is 14° and the wind is from the left of the true course line. Therefore, we subtract 14° from the true course of 090° and determine our true heading as 076°.

Once the true heading has been found, we then can apply the correction for magnetic variation and the correction for compass deviation to obtain a compass heading that will enable us to fly to our destination by dead reckoning.

### Flight Computations

Several other basic computations have to be worked out when using DR navigation. To find the amount of time a flight will take, the pilot divides the distance of the flight by the groundspeed. For example, if his destination is 360 miles away and his groundspeed is 90 mph, his simple computation shows that four hours will be needed to make the flight. $\frac{360 \text{ miles}}{90 \text{ mph}} = 4$ hours.

If the pilot knows the rate at which his aircraft uses fuel, he can also determine the amount of fuel required for a flight. He takes the total time of his flight (from the above example) and if his

aircraft burns six gallons of fuel per hour, then he can establish that his trip will require 24 gallons of fuel to fly 360 miles. The formula is Flight Time × Gallons/hour = Total Fuel.

## THE COMPUTER

We have determined our answers by using simple mathematical computations. Navigation computers have made computation much easier and faster.

Although we have not examined or used navigation plotters and computers in this chapter, we should become familiar with these tools of navigation. In Figure 25 we see the navigation plotter. It is primarily made for drawing courses and measuring angles and distances on aeronautical charts. The semicircular part is similar to a protractor and has two circular scales for measuring angles. In essence, the plotter is a combination ruler and protractor.

Figure 26 shows the common navigation computer used by most pilots. Several types of arithmetic problems constantly arise in navigation. Since speed and accuracy are of the utmost importance, one needs a method of solving these problems in a quick and accurate manner. The navigation computer gives a quick, simple, and accurate solution to a number of different problems. The most important problems solved by the computer are those involving time, speed, and distance.

We have mentioned the plotter and computer to familiarize you with these tools of air navigation. Although we did not use these tools in solving our example problems, we believe it important to realize that more sophisticated tools than a ruler and protractor

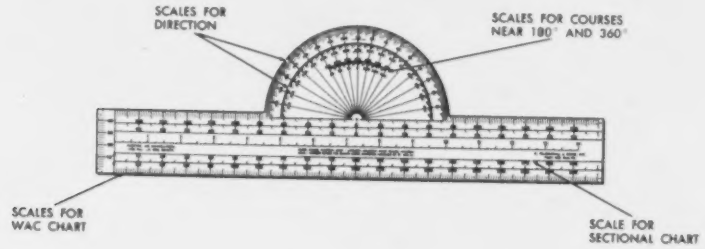



Figure 25. Navigation plotter.

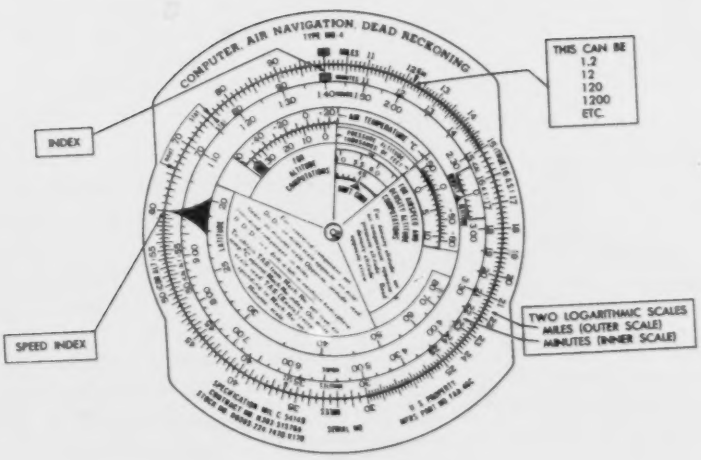



**Figure 26. DR computer.**

are used. An analogy might help strengthen the point. In early school years, students learn to extract square roots manually. In more advanced math, logarithms are used. In the same sense, the ruler and protractor you use with this booklet can be compared with the plotters and computers used by a navigator or pilot of today.

The next chapter will illustrate the use of navigation instruments. Dead reckoning navigation relies upon facts given to the pilot by the navigation and flight instruments. Instruments are important parts of navigation and Chapter 6 will explain the specific purposes of the various instruments.

## REVIEW QUESTIONS

1. **Explain fully what the common navigational term dead reckoning means.**
2. **Dead reckoning computations depend upon six basic factors. These factors are:**

   **(a)** **(d)**

   **(b)** **(e)**

   **(c)** **(f)**
3. **What are the purposes of a wind triangle?**
4. **What is the formula for determining total time in flight?**
5. **What is the formula for determining how much fuel is required for a flight?**
6. **There are six factors involved in the construction of a wind triangle. If _____ of these are known, the others may be found very easily by accurate measurement.**

## THINGS TO DO

1. Solve the following problem from the information given:
   (a) Distance to a given destination = 300 miles
   (b) Time in flight = 2½ hours
   (c) Groundspeed = _____
2. Construct a wind triangle and solve for the missing factors:

   Given: true heading = 080
   true airspeed = 150 mph
   true course = 070
   ground speed = 152 mph

   Find: wind direction
   wind speed
3. Construct a wind triangle and solve for the missing factors:

   Given: wind direction = 220
   wind speed = 20 mph
   true course = 340
   ground speed = 160 mph

   Find: true heading
   true airspeed
4. Invite a local citizen who is familiar with navigation to talk to the class about flight planning, how wind changes affect a flight, and the methods the navigator uses to insure a safe flight to destination.

## SUGGESTIONS FOR FURTHER READING

Federal Aviation Administration. *Path of Flight.* Washington, D.C.: U.S. Government Printing Office, current.

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*Chapter* 6

# Navigation Instruments

**THIS CHAPTER introduces the four basic instruments necessary for air navigation. Although other instruments are also used, these four are always required. The clock, airspeed indicator, magnetic compass, and altimeter are described and their uses explained. In addition, the various types of airspeed and altitude are presented. When you have studied this chapter, you should be able to: (1) list the four basic navigation instruments; (2) describe the functions and operations of these instruments; (3) know how to use each instrument; (4) list and explain the differences among the three kinds of airspeed; and (5) describe the five types of altitude.**

AIR NAVIGATION involves both vertical and horizontal movement, and the primary function of navigational instruments is to furnish continuous indications of direction, distance, and altitude. While a pilot of a modern airliner may face over three hundred instruments on his control panel, the pilot of a light aircraft faces relatively few. The difference is that the modern airliner has many gauges that give readings on different parts of the aircraft, such as engine performance and condition. Light aircraft still have numerous instruments, but never as many as a large passenger plane.

The minimum number of instruments required for even the simplest navigation is four: clock, magnetic compass, airspeed indicator, and altimeter, as shown in Figure 27. While there are many more instruments used in air navigation, this chapter is limited to those most commonly used by pilots of light aircraft.

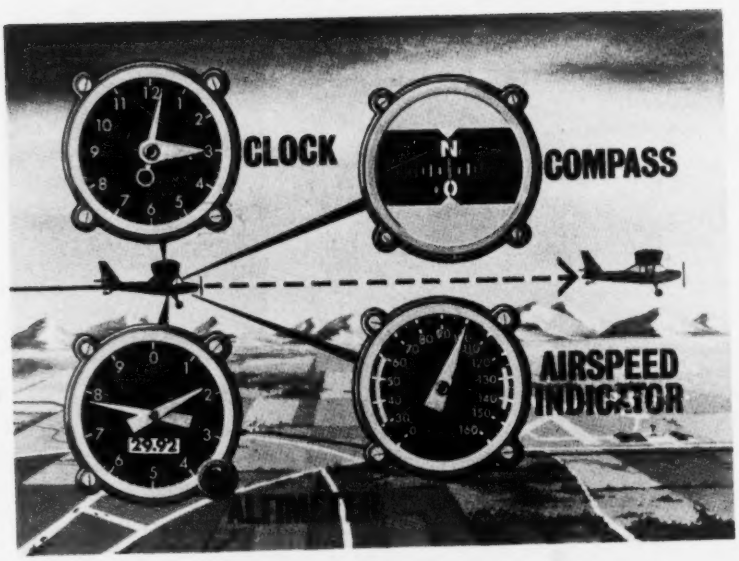


**Figure 27. Basic navigation instruments.**

In air navigation, as well as in every day affairs, time is an important factor. From start to finish of a flight, the estimated time of arrival (ETA) must be checked and rechecked. Of course, the time of arrival is dependent upon the speed of the aircraft and this speed is determined by dividing the distance by the elapsed time of the flight.

Another reason for having a reliable clock on board is to enable the pilot to determine fuel consumption. As we noted earlier, a pilot can estimate the amount of fuel his aircraft will require during a given flight under normal conditions. Sometimes, however, the pilot will encounter unexpected conditions that will prolong the flight time. He might decide to navigate around turbulent weather, for example. He might suddenly find the airport at his destination closed in, or planes "stacked up" waiting for a landing*. Both occasions demand that the pilot remain airborne longer than anticipated. Under such conditions the pilot must know how long he can remain in the air. In

* Stacked up refers to the situation where planes waiting to land are circling in the vicinity of the airport. They are flying at intervals and various altitudes to minimize collision hazards while awaiting their turn for landing clearance from the tower.

short, he must calculate his remaining flight time by using his aircraft clock to keep track of the total time his aircraft has been airborne. If he took off with just enough fuel for a four hour flight, he knows that he will have to land before that much time has elapsed.

Any good timepiece is suitable for indicating elapsed time. It is not necessary to have an elaborate clock or chronometer for simple navigation. One commonly used technique which minimizes errors in calculating elapsed flight time is to set the aircraft clock at 12 o'clock upon leaving the airport. With this arrangement, the pilot knows that all time recorded after both hands are "straight up" represents elapsed flight time. The correct time of day may be easily obtained from the pilot's own wristwatch.

Very often a clock with a sweep-second hand is required for some flight maneuvers. This hand can be set and reset for timing certain maneuvers, such as those required in landing approaches.

## AIRSPEED INDICATOR

An airspeed indicator measures an aircraft's speed in flight rather than its ground speed. Airspeed is the speed of an aircraft with respect to the air through which it moves. Groundspeed is the speed of an aircraft measured by the distance an aircraft travels over the ground. Because these two types of speed often differ, it is important that pilots do not confuse them. The airspeed indicator consists of a sensitive, airtight diaphragm, a linkage assembly, and a dial with a pointer. It measures the difference between the increased air pressure caused by the motion of the craft and the air contained in the case of the airspeed indicator, which is undisturbed atmospheric pressure at flight level.

As the speed of an aircraft increases, the impact air increases while the static or undisturbed air remains the same within the instrument case. This difference in pressure causes the diaphragm to expand, forcing the dial that is attached by mechanical linkage to move and indicate the airspeed upon the face of the indicator. This indication may be in miles per hour or knots, or both, depending upon the type of instrument. We might mention that all USAF aircraft read in knots.

The accuracy of the instrument is affected by instrument error, installation error, and the density of the air. Correction can be made by having the indicator checked periodically to insure its accuracy.

**Kinds of Airspeed**

A pilot knows that there are three kinds of airspeeds: (1) indicated airspeed; (2) calibrated airspeed; and (3) true airspeed.

Indicated airspeed is the instrument reading taken directly from the airspeed indicator. It has not been corrected for any variation in atmospheric pressure, installation error, or instrument error.

Calibrated airspeed is airspeed that has been corrected for installation error and possible instrument error. Because it is impossible to eliminate all instrument error, there is always a need to compensate for this error. At certain speeds and altitudes, the installation and instrument errors may amount to differences of several miles per hour. The greatest potential for error is in the low airspeed range. Indicated airspeed and calibrated airspeed are normally about the same in the high altitude and cruising airspeed ranges. To determine the calibrated airspeed, pilots refer to the airspeed calibration charts which allow for error caused by the instruments or installation. These charts are usually placed near the airspeed indicator or are included within the Airplane Flight Manual or owner's manual.

Since leaks may develop in the assembly, it is important to take good care of the entire airspeed indicator system. Dirt, dust, ice, and snow may damage the system and render the indicator inoperable. Even regular aircraft vibrations may influence the sensitive apparatus, forcing the indicator to give false readings. Therefore, it is imperative that the indicator be checked periodically to assure positive operating efficiency.

It is often difficult to find the actual airspeed of an aircraft. An airspeed indicator registers airspeed under standard sea level conditions. This is when the atmospheric pressure is 29.92 and the temperature is 15°C (55°F). When an aircraft flies to a higher altitude, the air density decreases, creating errors in true airspeed indications. In other words, for a given indicated airspeed, true airspeed increases with an increase in altitude.

Pilots use several methods to find their true airspeed. The first method, that of using a computer, is the most accurate. This method corrects the calibrated airspeed for temperature and air pressure by using the airspeed correction scale on the computer.

The second way of finding the true airspeed is not as accurate as the first, but it is handy when there is no computer aboard. The simple rule to follow is to add to the indicated airspeed 2% of the in-

dicated airspeed for each 1000 feet of altitude. For example, the indicated airspeed is 120 mph at an altitude of 4000 feet. The true airspeed would then be:

2% × 4 = 8% (.08)
120 × .08 = 9.6
120 + 9.60 = 129.6 mph (TAS)

A third method is similar to the one above. Simply add to the indicated airspeed two mph for each 1000 feet of altitude. If we use the figures from the last example, we see that this method gives us an answer of 128 mph (TAS). Neither of these two answers is precisely correct, but these computations give quick approximations, and are used frequently by pilots. Many modern aircraft are equipped with true airspeed indicators that require no corrections.

## MAGNETIC COMPASS

The magnetic compass is the primary means of indicating direction. It allows a pilot to turn his aircraft to a magnetic heading and maintain it. Another method of obtaining directional readings is to use the directional gyro. This instrument provides accurate headings regardless of the attitude of the aircraft. However, we will only examine the magnetic compass in this chapter. Although there are several types of compasses, we will look at the simple flotation type used in most light aircraft.

Magnetized steel rods within the compass are attracted to the magnetic poles of the earth. These steel rods are mounted on a float which is encircled by a compass card. This whole structure is then enclosed in a glass-windowed case. The case is filled with a solution of white, acid-free liquid that prevents excessive movement of the compass card.

Principal directions—north, south, east, and west—are represented on the compass card by the letters N, S, E, and W. Headings that fall between the principal directions are indicated by numbers placed at 30° intervals. These numbers do not have the last zero and so 30° appears on the compass card as 3 and 190° as 19. Headings between these numbers are represented by small vertical lines placed at 5° intervals. While these are the larger markings used for quick reading, every degree is shown on most compasses.



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Directions are read with a reference line mounted behind the glass face of the compass case. Because turns, dives, climbs, and changes of airspeed affect the behavior of the magnetic compass, readings are taken only when the aircraft is flying straight and level at a constant speed. Modern military aircraft have highly sophisticated compass systems that have eliminated many common compass errors.

## ALTIMETER

The altimeter measures altitude, the vertical distance above a level plane of reference, such as sea level. Because it is the only instrument that gives altitude information, it is one of the most important instruments in an airplane. Most light planes use an altimeter that is an aneroid barometer apparatus. It measures the atmospheric pressure at flight level; that is, the weight of the air above the craft. As previously noted in another section, air pressure (or air weight) decreases as altitude increases. As air pressure around the altimeter's sealed diaphragm decreases, the diaphragm expands.

When the airplane returns to a lower altitude and the atmospheric pressure increases, the diaphragm contracts. The results of this expansion and contraction are transmitted by levers and gears to indicator hands on the dial of the altimeter. The pressure altitude is shown on the dial as feet above sea level.

The dial face of the altimeter is graduated with numerals from 0 through 9. The three pointers on the face of the altimeter each represent different altitude measurements. The large 100 foot indicator makes one complete revolution for each one thousand feet of altitude. Each numerical reading is in hundreds of feet for this pointer.

The intermediate, or second pointer, makes one full revolution for each ten thousand feet of change in altitude. This scale is then in thousands of feet. The small third pointer reads in tens of thousands and one revolution represents one hundred thousand feet of change. This is illustrated in Figure 28.

With an increase in altitude, the altimeter will give readings which are not exactly correct. To obtain exact readings, the indicated reading must be corrected for atmospheric pressure, temperature, and instrument error.

Figure 28. Pressure Altimeter.

To achieve vertical clearance, all aircraft in a given area are given a particular pressure level known as an altimeter setting. Altimeter settings may be generally defined as the pressure in inches of mercury of the reporting station reduced to sea level. Prior to takeoff, the pilot should turn the knob on the altimeter until the correct altimeter setting, which is furnished by the tower, is set on the pressure scale visible through the Kollsman window on his altimeter.

Setting the pressure scale to altimeter setting causes the altimeter to read indicated altitude. Flying indicated altitude insures traffic separation, since, in passing, the different altimeters are equally affected by whatever pressure and temperature conditions may exist. The pilots need not make allowance for nonstandard atmospheric conditions but must keep their altimeters adjusted to the latest altimeter setting. These settings can be obtained from radio stations or control towers along the immediate route.

If no means were available to change the altitude setting, flight could be extremely hazardous, especially while flying over mountainous areas. A change of $\frac{1}{10}$ of an inch of mercury in the pressure setting will result in a change of 100 feet in altitude. If there is a change of one inch in the pressure setting, the altimeter reading will be changed by 1000 feet. While flying along a flight

path, the pilot must set his altimeter to the readings given by the nearest stations. The altimeter can be one of the most important of the navigational instruments, but every pilot must understand its restrictions. Careful usage coupled with periodic checks make this instrument extremely valuable.

### Types of Altitude

Pilots are usually concerned with five different types of altitude:

Absolute altitude: height of an aircraft above the terrain over which it is flying.

Indicated altitude: uncorrected altitude read directly from the altimeter after it has been set at the current altimeter setting.

Pressure altitude: altitude read from the altimeter when the setting is adjusted to 29.92; used to compute density altitude, true airspeed, true altitude, etc.

Density altitude: the pressure altitude corrected for temperature variations; important because it is directly related to aircraft takeoff and climb performance.

True altitude: actual height above sea level of an aircraft; the actual altitude, usually expressed as "9,500 ft. MSL"; MSL is mean sea level; airport, terrain, and obstacle elevations are all stated in terms of true altitudes.

## OTHER FLIGHT INSTRUMENTS

We have looked at the four most common navigational instruments. We have seen what they do and how they operate. Before we continue, let's look for a moment at the other helpful instruments. These instruments, while not specifically navigational instruments, greatly assist in making air navigation decisions. The most common instruments are the vertical velocity (or climb rate) indicator, the turn-and-slip indicator, and the gyro horizon (or attitude indicator). The instruments, while definitely helpful to air navigation, are basically flight instruments. For this reason, they are discussed in detail in the AE II booklet *Theory of Flight*.

Instrument navigation has made air travel safer than at any previous time. With instruments, a pilot can still fly his craft in weather that makes all other forms of navigation unusable.

This topic of weather is of extreme interest to pilots. Chapter 7 will show us how pilots may obtain various forms of weather information and how this information is compiled by weather stations.

## REVIEW QUESTIONS

1. **Why are navigation instruments important to a pilot?**
2. **What are the four basic navigation instruments and how are they used?**
3. **List and explain the three types of airspeed.**
4. **What is the primary means of indicating direction in an aircraft?**
5. **How does a pilot determine a craft's height above ground?**
6. **List and explain the five different types of altitude.**
7. **List three other types of instruments that aid in navigation.**

## THINGS TO DO

1. If cut-away models of the common aircraft instruments are not available, try to locate some instruments that have been discarded from either civilian or military sources. Ask your instructor's advice about the best way to make them into cut-away mock-ups that will allow your classmates to understand how the instruments work.
2. With the assistance of a local weather office, draw a chart that explains the differences between indicated, pressure, density, absolute and true altitude.

## SUGGESTIONS FOR FURTHER READING

CONROY, CHARLES W., and HAROLD E. MEHRENS. *Navigation and the Weather.* n.p.: Civil Air Patrol, n.d.

LYON, THOBURN C. *Practical Air Navigation.* Denver: Jeppesen & Co., 1966.

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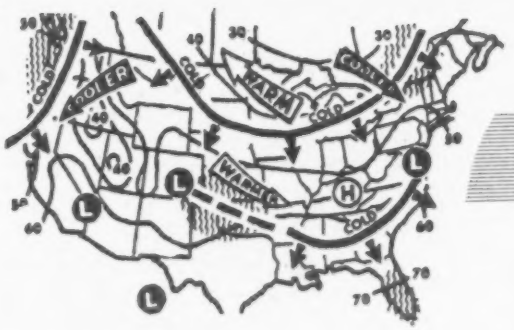
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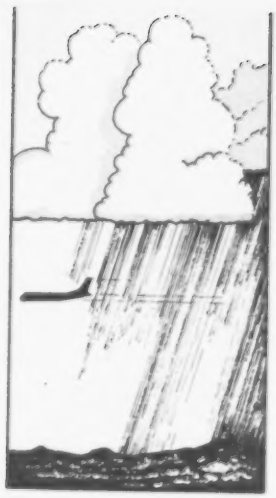

# Weather Information Available to Pilots

**THIS BRIEF CHAPTER is designed to remind the student of the types of weather reports that are available to the pilot from the Weather Bureau. Coupled with the AE–1 booklet, *Weather*, this chapter should leave the student with an awareness of the importance of weather considerations on routine flights. When you have studied this chapter, you should be able to: (1) list and explain the various types of weather information available; and (2) know where to get these reports.**

IN THE AE I BOOKLET, *Weather*, our objective was to learn about the elements of weather and man's efforts to predict its behavior. In this chapter, our focus will be on the pilot's utilization of available weather data.

Highly trained personnel at weather stations observe the weather in their immediate areas and record all information (Fig. 29). Weather observations are then sent via teletype to all other weather stations, airports, and agencies utilizing this teletype service.

From these close observations, trained personnel then make predictions for future weather conditions for their respective areas. These forecasts are also sent across the Nation via teletype. A pilot may call any weather station or airport along his course and obtain the weather conditions and forecasts for his entire flight.

Figure 29. Meteorologists make up-to-date weather information available.

## REPORTS AND FORECASTS

Weather information is provided to pilots in two forms: reports and forecasts. Reports are compiled from visual observation of existing weather conditions. Forecasts are obtained by combining reports with a knowledge of meteorology to forecast as accurately as possible the weather for the next several hours.

Although there are many different types of reports and forecasts issued regularly, we will discuss only those most frequently used by pilots. These are Hourly Sequence Reports, Pilot Reports, Winds Aloft Reports, Maps, Area Forecasts, and Terminal Forecasts.

### Hourly Sequence Reports

Hourly Sequence Reports are produced and released about every hour, 24 hours a day. Personnel at weather stations and FAA communications stations across the Nation observe local weather conditions. These local observations are then reported to all other stations via teletype. Any airport or agency that is part of the teletype system also receives the most up-to-date weather information

from across the United States. Because these reports are made so frequently, and since they are reports of existing weather conditions from more than 500 stations, hourly sequence reports are of great value to the pilot in planning his flight.

### Pilot Reports

Another way to obtain weather information is to examine reports directly from pilots who have flown through unusual weather conditions. Reports of unusual conditions observed during flight are sent by the pilot to the nearest FAA communication station or weather bureau for immediate distribution to other pilots. This type of report, called PIREPS, is important for two reasons: (1) this information is a good supplement to information gathered by ground observers who often cannot determine specific conditions at varying altitudes; (2) pilot reports serve as gapfiller reports on unobserved weather between stations.

### Winds Aloft Reports

Periodic checks are made by weather stations to determine wind velocity and direction. This wind information, known as the Winds Aloft Report, is sent via teletype to all other stations. The pilot can then select the best altitude at which to fly.

### Area Forecasts

The Area Forecast is given at 6 hour intervals. Every major weather bureau station forecasts the weather for its particular area for the next 12 hours. This forecast includes such information as expected clouds, icing, weather conditions, and turbulence. As with reports, these forecasts are sent via teletype to all stations, agencies, and airports linked by the teletype system.

### Terminal Forecasts

Terminal forecasts differ from area forecasts only because terminal forecasts are made by every station, regardless of size and importance. Trained forecasters predict the weather for the next 12 hours and these forecasts are also distributed by teletype.

## WEATHER MAPS

As previously noted in another chapter, maps and charts have a major role in air navigation. Maps are also of great importance in

weather forecasting. Every six hours, observers at each weather station report the existing weather at their specific station to a central station. The personnel at the central station use these reports to make a map of the weather conditions throughout the entire country. This type of map, along with others which show existing conditions at the surface and at several specific altitudes, is sent via a facsimile machine to each weather station. In this manner, every weather station in the Nation has the most complete and accurate weather information.

After all the information is obtained, the next step is to make some evaluation of the conditions and then forecast the weather for the next few hours.

The United States Weather Bureau provides all aircraft pilots with an abundance of meteorological information. This information is necessary for safe and efficient flights. Pilots must have advance warning of stormy weather. No pilot wants to become airborne and discover that a strong front of thunderstorms is directly in his line of flight. Weather information is widely disseminated and any pilot in the United States has only to dial the nearest weather station to obtain the latest weather data.

## REVIEW QUESTIONS

1. **List three ways in which pilots may obtain weather information.**
2. **What are PIREPS and of what assistance are they?**
3. **How are weather reports and forecasts sent from station to station?**
4. **Why is advance weather information of importance to pilots?**
5. **How long a period of time is covered by area forecasts?**
6. **How often are terminal forecasts made?**

## THINGS TO DO

1. Break the class into teams and have each team use whatever resources it can find to forecast the weather for a 3 to 5 day period during the next week. Following the days forecasted, have each team explain the methods used and what the results were.
2. Have a local weather station provide a forecast so that a 2 to 3 minute weather report can be given at the beginning of each class while this chapter is being studied.

## SUGGESTIONS FOR FURTHER READING

CONROY, CHARLES W., and HAROLD E. MEHRENS. *Navigation and the Weather.* n.p.: Civil Air Patrol, n.d.

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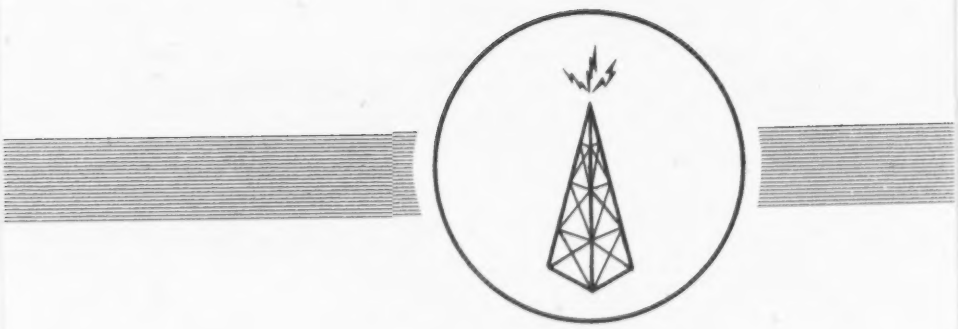

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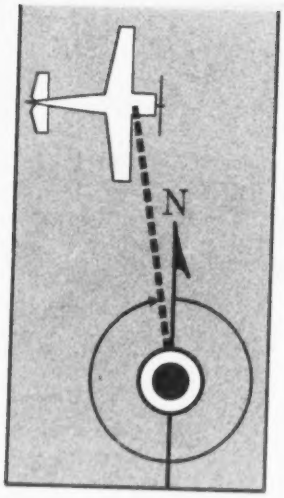


# Radio and Electronic Navigation

**THIS CHAPTER introduces the various types of radio and electronic navigation and presents some information about the many types of navigational aids employed in the United States and throughout the world. The chapter ends with a short section about celestial navigation. When you have studied this chapter, you should be able to: (1) explain the methods of radio navigation; (2) describe the principles involved in the operation of radio-electronic navigation systems; (3) explain the wide variety of navigation aids; and (4) describe some of the more complex methods used in air navigation.**

BY THE TIME we finish reading this chapter, we should be able to distinguish between the different types of radio and electronic navigation. Further, we should understand the basic operating procedures of each type.

## LF/MF RADIO RANGE

One of the first methods of locating airways by electronic means was the low-frequency/medium-frequency (LF/MF) radio range. Although several other types of radio and electronic ranges have been established to aid in air navigation, the LF/MF range is still widely and successfully used. One reason for the continued use of

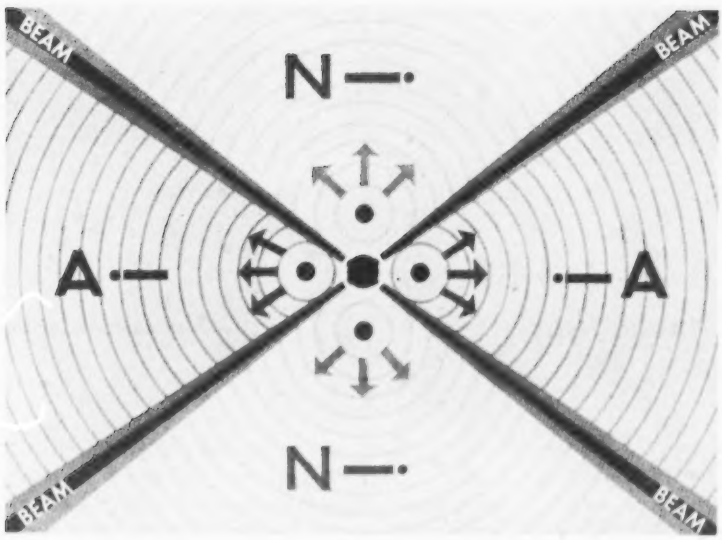


Figure 30. LF/MF radio range.

the LF range is that aircraft only need an LF/MF radio receiver. Another advantage of the low frequency radio range is that its broadcasts can be tuned in at low altitudes and can even be received on the ground. This aids the light aircraft which usually flies at altitudes below 18,000 feet.

After serving as navigational aids along our country's airways for almost 25 years, the LF/MF radio stations are being replaced with improved electronic equipment. Less than one hundred LF/MF stations will be maintained and these will be chiefly used for weather reports and limited navigational information.

Since this is one of the first types of radio aids to air navigation, we will examine how the LF/MF radio range station operates. If we look at Figure 30, we see that the low frequency station transmits signals in such a way that an overlapping of signals defines four different courses. By using special antennas, the Morse Code for A (.—, dit da) is broadcast into two opposing quadrants of the range about a station. Morse Code for N (—., da dit) is broadcast into the other two quadrants. These signals are of equal amplitude and when they overlap along the boundaries of the quadrants, they form

a steady hum which signifies the course to the station. This steady tone created by the merging of the two signals, A and N, is called the *beam*.

The radio beam is uninterrupted except when broken for station identification signals and weather reports. Most stations have a three letter identification signal which is broadcast every thirty seconds. Once a pilot has located a beam and has determined from the letter identification that he has approached the correct airport, he must determine which quadrant he is in and proceed along the airway.

Unless a pilot is flying on or near a beam, he hears either the A (dit da) signal or the N (da dit) signal. The pilot must then make a few basic movements that will determine where he is in relation to the station. Merely hearing the hum of a beam is not enough to lead to a station. The plane may be flying over a beam and yet the pilot may not know in what direction he is flying; toward the station or away from it. Obviously, a careful reading of his aeronautical charts would help locate his position, but often it is difficult to determine the exact quadrant.

To explain how a pilot locates his position about a range station, the diagram in Figure 31 is helpful. Planes "A" and "C" receive "N" signals but do not know what quadrant they are in, North or

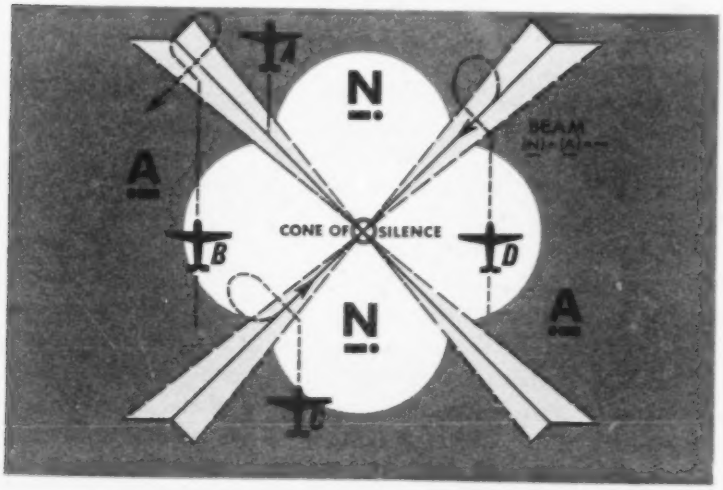


Figure 31. Locating position about an LF/MF station.

South. Both continue flying north. Plane "A" gets a fading signal, crosses no beam and deduces that he is in the North quadrant. Plane "C" gets a stronger signal, crosses a beam, and knows that he is in the South quadrant. Plane "A" turns about, picks up a beam and heads toward the station. Plane "C" turns and picks up the beam that is just crossed and follows it to the station.

Planes "B" and "D" are receiving "A" signals, but do not know if they are in the East or West quadrants. Both planes maintain their northerly courses and both receive fading signals. However, both of them soon intercept beams. The planes make a "procedure" turn, a move used to help determine position about a range. Plane "D" stays on the beam and knows that he is in the East quadrant. However, plane "B" goes through the beam and determines that he is in the West quadrant. The pilot must then alter his course and once again pick up the beam, this time heading toward the station.

Although the LF/MF radio range station has been used for many years, the system it provides is not the easiest for pilots to use and sometimes creates confusion. Other devices, such as the automatic direction finder, have been developed to replace the low frequency radio range. Let's look at several of these electronic navigational aids.

## VOR STATIONS

In recent years, the LF/MF radio station has been replaced to a large degree by the very high frequency omnirange (VOR). VOR stations provide the most extensively used radio navigation system for aircraft. The name of these stations has been shortened to VOR or omni. VOR means *V*ery high frequency *O*mni*R*ange. Omni means all. An omni station is a very high frequency station that transmits radio beams in all directions. Figure 32 illustrates this by showing these radio beams, called radials, extending out from the station like spokes from the hub of a wheel. Each beam or radial is identified by its magnetic direction *from* the station. Instead of being limited to the four courses of the LF/MF radio range, a pilot flying VOR may fly to or from a station by following the proper radial, regardless of his location within the range of the station.

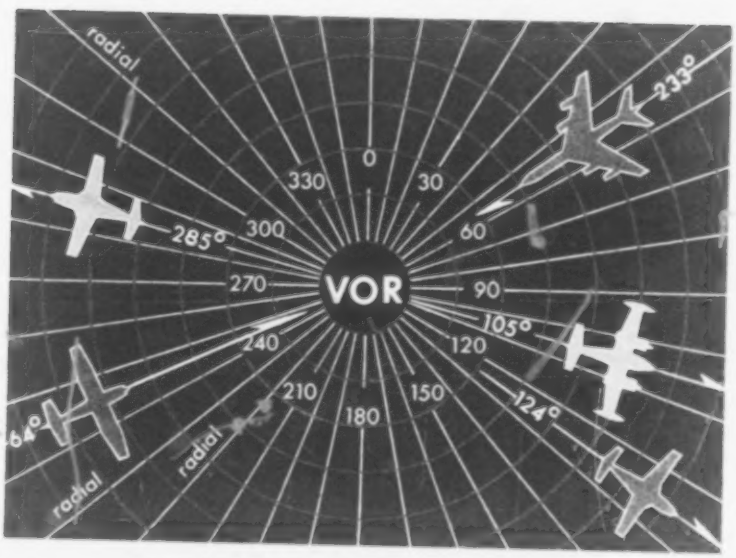


Figure 32. Very high frequency omnirange station.

Whereas LF/MF radio range stations have a great amount of static and require complex orientation procedures,* the VOR is a simple instrument to use. VOR signals are relatively free of static and wind or drift correction angles do not have to be used because VOR radials provide their own continuous directional guidance. Bearings taken on two VOR stations may be used quickly to locate on a chart a plane's position.

### VOR Features and Operations

Each VOR receiver has four principal features. The *frequency selector* tunes the receiver to a desired VOR station. The *course selector* identifies the proper course to a VOR station. The *To-From indicator* informs the pilot that a selected course is either to (toward) or from (away from) the tuned station. The *Left-Right indicator* (course deviation indicator) tells the pilot that he is on course or left or right of course.

It is very simple to operate a VOR receiver. Aeronautical charts list all of the broadcast frequencies used by VOR stations. Each

* See pages 73–76 about procedures.



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VOR station is identified by a three letter call sign that is broadcast in Morse Code. Also, some stations identify themselves by voice recordings that are alternated with the code.

To fly *to* a VOR station, a pilot must first tune the VOR receiver to the frequency of the station and identify the station either through Morse Code or voice recording. He then has a four part procedure to carry out. First, he tunes the course selector until the Left-Right indicator is centered. Then he checks the To-From indicator to make sure that it reads TO. If the indicator reads *from*, he must turn the course selector halfway around until a TO indication appears. The third step is to observe the heading indicated by the course selector. This is the magnetic bearing to the tuned VOR station. The last step is to turn the aircraft until the magnetic compass indicates the same general direction as the course selector.

As long as the Left-Right indicator remains centered, the aircraft is on course to the station. Should the indicator point either left or right of the center line, small corrections in heading should be made to regain the proper course.

The procedure used to fly *away from* a VOR station is very similar. The five step procedure is: (1) tune the VOR station, (2) identify the station (Morse Code or voice recording), (3) rotate the course selector to the correct outbound bearing and center the Left-Right indicator, (4) be positive that the To-From indicator shows From, and (5) turn the aircraft to the compass heading that corresponds with the course indicated by the course selector.

If the Left-Right indicator shows that the aircraft is either left or right of the course, small corrections in heading will return the aircraft to the desired course. The aircraft will fly directly away from a VOR station if the Left-Right indicator is centered.

## DISTANCE-MEASURING EQUIPMENT (DME)

Distance-measuring equipment (DME) continuously measures the slant distance of an aircraft from a known point on the ground. The ground unit consists of a combined DME receiver and transmitter. This ground-based system is called a *transponder*. Each aircraft equipped to use DME signals has a similar unit. The aircraft unit is called an *interrogator*. The interrogator emits a pulse (signal) which is received by the ground-based transponder. The transponder then replies to the interrogator with a similar signal. This process is illustrated in Figure 33.

The aircraft's DME unit measures exactly the elapsed time between the transmission of the interrogator's signal and the reception of the transponder's reply. This measurement, called the *slant range*, is instantly converted by the airborne unit into distance. The distance in miles is automatically and continuously shown by a dial on the instrument panel.

When DME is used in combination with VOR, a pilot can tell at a glance the direction to a tuned station and the distance to or from it. VOR and DME are two of the new radio and electronic systems that have made air navigation safe for modern air transportation.

## VORTAC

Tactical Air Navigation (TACAN) is a military system of radio-electronic navigation that provides bearing information like VOR and distance information like DME. The need for a common system of bearing and distance information to both military and civilian pilots has resulted in a combination of VOR/DME and TACAN. This combined system, called *VORTAC*, is being put into operation for joint military-civilian use.

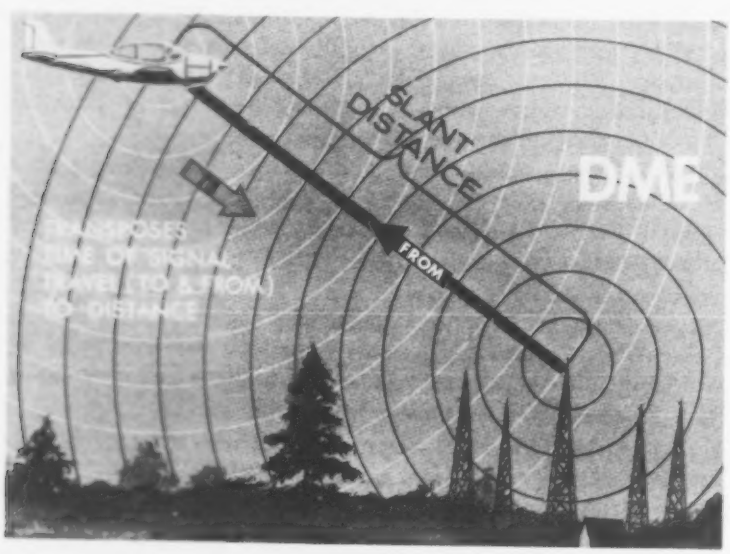


Figure 33. Distance-measuring equipment.



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Figure 34. VORTAC station.

A VHF omnirange (VOR) and a UHF (ultra high frequency) TACAN transponder make up a VORTAC station. If an aircraft is equipped with a complete TACAN unit, the aircraft can receive both directional guidance and distance information from the TACAN transponder at a VORTAC station.

Aircraft equipped with only a VOR receiver may receive directional guidance from the VOR of a VORTAC station. A separate aircraft distance interrogator is used by VOR equipped aircraft to obtain distance information from VORTAC stations.

A pilot in a civil aircraft may tune his VOR receiver to the VOR frequency of the VORTAC station and receive bearing information. If his plane is equipped with a distance-measuring device that is usable with TACAN, the pilot may also obtain distance information from the VORTAC station's TACAN unit.

A pilot flying a military aircraft equipped with TACAN may obtain both bearing and distance information from the TACAN unit of the VORTAC station.

VORTAC facilities are being used more each year. The continued construction of VORTAC stations, like the one in Figure 34,

and the increasing availability of low-cost aircraft equipment are promoting the use of VORTAC stations. VORTAC stations now compose the majority of the radio and navigational aids located along our airways.

## AUTOMATIC DIRECTION FINDER (ADF)

The automatic direction finder receives radio guidance signals from stations such as radio beacons, four-course ranges, and commercial facilities. ADF equipment indicates the direction of the station being received, in relation to the heading of the aircraft. In Figure 35 we see our plane flying north. The ADF indicates that a station is located 35° (to the right) of our position. In Figure 36 we have turned our craft 35° E and are heading directly toward the station. When the ADF needle is on zero, the aircraft is on course to the tuned station.

Automatic direction finders have several uses. Perhaps the most common use is in "homing." A pilot tunes in a desired station and then flies directly to that station by keeping the ADF indicating needle on zero. As noted, the aircraft is on course when the needle

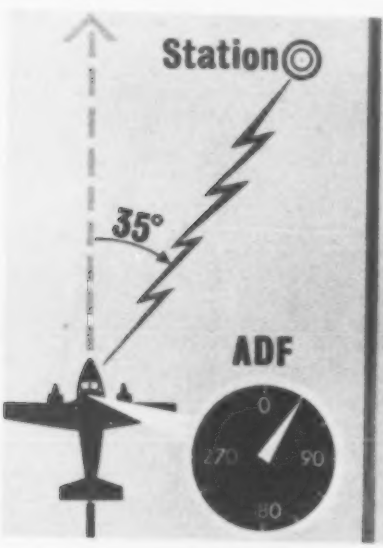


Figure 35. ADF station right on heading.

Figure 36. ADF station on course.

is on the zero mark, however, if the station is passed, the needle will turn around to the 180° mark, indicating that the station is behind the plane.

Other uses of ADF are in plotting position. A pilot may tune to two or more stations and plot the bearings received on an aeronautical chart to determine his position. He may also tune to a single station and obtain a bearing. He then can combine this line of position with a radio range signal to fix (locate) his position. Automatic direction finders, helpful aids to air navigation, are just part of an increasing navigational system established across the United States.

## RADIO DIRECTION FINDING (RDF)

Radio direction finding stations are ground-based radio compasses that are mainly used for emergency homing. Any pilot whose aircraft is equipped with a radio transmitter and receiver may request navigation assistance from direction finding stations. If an aircraft experiences difficulty while flying, the pilot can transmit a steady signal to the direction finding station and the station can determine

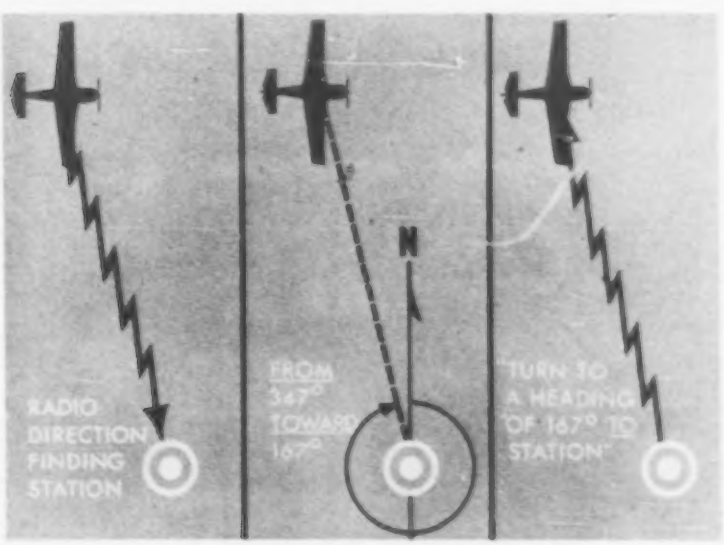


Figure 37. Radio direction finding station.

the direction of the signal. Personnel at the station then notify the pilot of the heading he should fly to reach the station. This is illustrated in Figure 37.

Another use of RDF stations is that of plotting positions of aircraft. When two direction finding stations operate together, one station may use the bearings received by the other to fix the position of the aircraft by triangulation. The two stations and the aircraft act as points of the triangle. Both stations (base points) take bearings on the aircraft, and the position of the aircraft is the point where the bearings intersect. Once this position has been determined, it can be related to the aircraft pilot in terms of latitude and longitude.

Radio direction finding stations provide valuable navigational aids. Whenever a pilot is in trouble while in the air, he can call an RDF station and be guided home. Aeronautical charts and publications list the information necessary to use radio direction finding stations.

Two other types of radio and electronic navigation facilities are LORAN and Doppler radar. We will briefly look at these two methods of air navigation.

## LORAN

Long-Range Navigation (LORAN) is used mainly by aircraft flying over ocean routes. Practically all ocean areas of the Northern Hemisphere are served by LORAN stations. Aircraft must have a special LORAN receiver and special LORAN navigation charts to use this system.

LORAN stations are operated in pairs, each pair consisting of a *master* station and a *slave* station. Figure 38 shows the master (M) station and the slave (S) station sending out their signals to the aircraft flying between them. A pilot first tunes his LORAN receiver to the desired pair of stations. The first signal received is from the master station. After a set delay, the slave station emits its signal on the same frequency. Although the master signal is always received first, the interval between the arrival of the master and slave signals varies according to the position of the aircraft. The LORAN receiver within the aircraft measures this time difference between the two signals.

This time difference remains constant at any one location, but there is more than one point from which the same time difference



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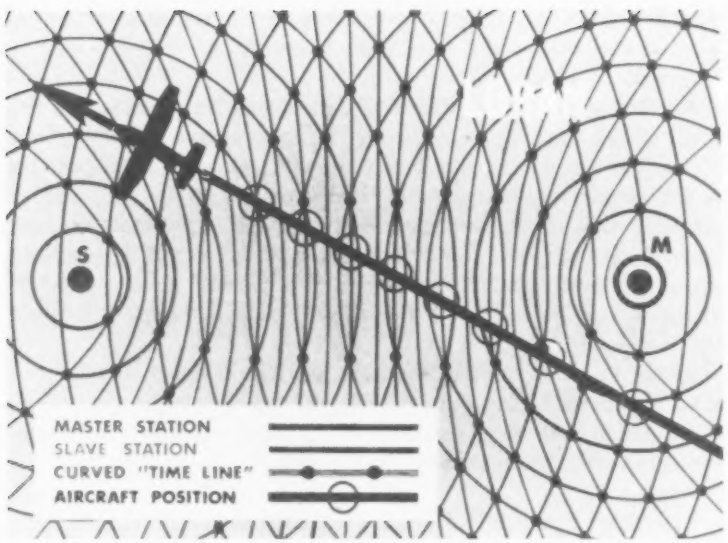



Figure 38. Long range navigation system.

may be measured. A line drawn through all such points takes the shape of a curved line called a *hyperbola.* LORAN navigation charts include a series of hyperbolas that represent various time differences for LORAN signals.

The pilot locates on his LORAN chart the hyperbola for the time difference measured by his LORAN receiver. Since this curved line passes through all points from which this time difference may be obtained, the aircraft is located somewhere along this line. The hyperbola on the LORAN chart that corresponds to this time difference is the LORAN line of position on which the aircraft is located.

A second set of LORAN signals is received and the time difference for this set is determined by the receiver. This time difference is also plotted on a LORAN hyperbola chart and another line of position can be established. The position of the aircraft is then determined as the point where these two lines intersect.

## DOPPLER RADAR NAVIGATION

Military and civilian pilots have increased their use of the Doppler radar navigation system. Since it does not rely on ground navigation aids and is essentially self-sufficient, Doppler navigation is

specially valuable on inter-island flights, on transoceanic routes, and in remote areas. For this same reason the Doppler system has the valuable potential of opening new world air routes over remote areas where it would be impractical to locate ground facilities.

The Doppler principle is seen in a common experience. As a car approaches you at high speed, its sound remains fairly steady and slightly higher than true pitch. The speed of the approach is being added to the speed of sound, resulting in a higher frequency of sound received. As the auto passes you, its sound drops quickly to a frequency below its true pitch and remains approximately at the lower sound as the car moves away. Now the travel speed is being subtracted from the sound speed, making the lower pitch. If we could measure this change in pitch, and if we knew when the signal was sent, we could tell distance exactly. We *can* do these things, and the method is called Doppler.

The system works through an electronic computer that gives the pilot distance information. A typical Doppler set transmits four radar beams downward at such angles that they outline the corners of a large square beneath the aircraft. As the distance between an observer and a source of constant vibration increases or decreases, the frequencies appear to increase or decrease. This Doppler effect* forces the frequency of the radar signals reflected back to the aircraft to be shifted in proportion to the speed of the plane. The frequencies of the reflected signals are compared with the original signals and the difference is measured by the Doppler set. The data that is obtained from each of the four beams is then fed into a computer. The computer then calculates the drift angle of the aircraft and its exact groundspeed.

Indicator dials on the aircraft's Doppler set have several functions. One dial selects the course while another sets the distance to be flown. A *miles-to-go indicator* subtracts the miles flown and gives a continuous indication of the remaining distance. Another indicator shows when the aircraft is deviating from its desired course and indicates this deviation in miles. The Doppler system constantly adjusts to changes in wind direction, aircraft attitude, and engine power and gives instantaneous readings. Some sets have a small light that alerts the pilot when the aircraft is within 10 miles of the destination. The electronic computer may also be employed with an automatic pilot used in many of today's aircraft.

* *Principle* established in 1892 by Christian Johann Doppler, a German mathematician.

## NAVIGATION AIDS

Because of the increasing number of aircraft flying our Nation's airways, it has become imperative that a system of navigational aids be established to help control air traffic. Some of these aids assist the pilot in flying from place to place. Others are used to improve flight safety and to control air traffic. Still others provide important landing assistance. The role of local, national, and international governments in establishing and operating these facilities is explored in the AE I booklet *Aerospace and the American People*.

The Federal Aviation Administration, in its constant effort to promote air safety and management, has established and now operates several types of navigational aid facilities. We will look briefly at these aids to see what they are and what purposes they serve.*

### Radio Aids

Radio aids to navigation help the pilot in several ways. The following list contains some of the more common ways in which radio aids assist aircraft pilots.

1. Keep craft on course by warnings of any departure from the radio path.
2. Point out destination.
3. Provide weather information.
4. Provide altitude information.
5. Provide landing instructions from traffic control.
6. Enable pilot to "see" through poor visibility.
7. Guide craft to safety when visual ground contact is impossible.

### Electronic Aids

The following is a brief look at the wide range of electronic navigational aids that are used today.

*Flight Assistance*

1. Course-line computer: use VOR and DME signals to calculate course deviation and distance-to-go within range of tuned station.
2. Pictorial computer: shows aircraft's position on a chart.

* *Civil Aviation and Facilities, AEII*, thoroughly describes the various navigational aids and explains their uses.

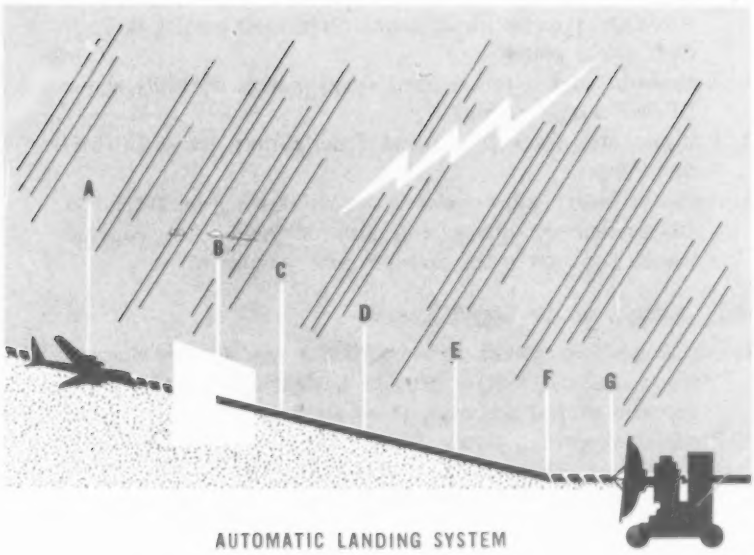
3. Radio marker beacons: used with LF/MF radio ranges, provide exact position identification for aircraft passing through their signal patterns.
4. Z-markers: emit a cone-shaped signal pattern vertically above LF/MF range stations.
5. Fan markers: transmit elliptical signal pattern across LF/MF range legs.
6. Airborne radar: allows pilot to see checkpoints on ground in all weather conditions, can also determine GS, courses, winds, and best paths through poor weather.

*Flight Safety and Air Traffic Control*

1. Air Route Surveillance Radar (ARSR) and Airport Surveillance Radar (ASR): provide navigational guidance and separate aircraft according to air traffic rules.
2. Precision Approach Radar (PAR): visually displays instrument approach zones.
3. Airport Surface Detection Equipment (ASDE): controls ground traffic.
4. Automatic Ground-Air-Ground Communications Systems (AGAGCS): automatically change course and altitude of aircraft in flight by transmitting signals to aircraft's automatic pilot.
5. Airborne anticollision devices: use radar and infrared sensing devices to warn of impending collisions.

*Landing Assistance*

1. Radar Approach Control (RAPCON): military radar which controls arriving or departing IFR traffic.
2. Ground Controlled Approach Radar (GCA): transmit landing instructions to pilots by voice radio.
3. Instrument Landing System (ILS): uses directional radio transmitters and radio marker beacons to show direction of runway, angle of glide path, and position of aircraft along proper approach route.
4. Automatic Landing System (ALS): combines the use of radar and computers with an automatic pilot to provide exact approach control and landing assistance in all weather conditions. The entire ALS operational sequence is illustrated in Figure 39.




AUTOMATIC LANDING SYSTEM

A - Final Approach Position

B - As Aircraft Flies through Window Radar Automatically Locks On

C - Pilot Engages Autopilot

D - Flight Path Converges with Pre-Selected Path. Constant Glide Slope is Maintained. Landing System Commands Straight and Level Flight if Approach is Missed.

E - Aircraft is Automatically Flared

F - At Touchdown Pilot Disengages Autopilot

G - As Plane Passes, the Radar Automatically Begins Cycle for Next Plane

Figure 39. Automatic landing system.

### Flight Publications

Another example of governmental assistance to aviators is the publication of navigation information. These publications provide excellent sources of information of importance to the pilot. We have listed several of the major flight publications produced by the FAA and other government organizations.

AIM.—The *Airmen's Information Manual* (AIM) is the basic information manual for airmen in the United States. Published by the FAA, it contains

complete data about airports, radio and radar facilities, lighting aids, search and rescue procedures, commercial broadcasting stations, weather services, and air traffic control procedures.

NOTAMS.—*Notice to Airmen* (NOTAMS) announce permanent changes in facilities and temporary hazardous conditions at civil airports. They also contain revisions in existing facilities, new procedures, special rules, and other information of interest to pilots.

*International Flight Information Manual.*—Another publication of the FAA is the *International Flight Information Manual* that is issued monthly. This manual is further supplemented by the weekly publication of the *International NOTAMS*. Contained in the FAA manual is information about foreign entry requirements, airports of entry, pertinent regulations, restrictions, and passport, visa, and health requirements established by each country.

FAR's.—*Federal Aviation Regulations* (FAR's) provide traffic rules of the air in the United States. Private, commercial, and military pilots adhere to these FAA publications as a requirement of safety. Those regulations of special interest to airmen are: certification of pilots and instructors, general operating and flight rules, and abbreviations and definitions. Military aircraft only depart from them during special training or combat missions. CAB Safety Investigation Regulations establish other important rules pertaining to aircraft accidents, in-flight hazards, overdue aircraft, and safety investigations.

*International Rules of the Air.*—*International Rules of the Air* have been adopted by the member nations of the International Civil Aviation Organization (ICAO). They provide the basic regulations for control of all flight operations in the international aerospace.

FLIPs.—Other special flight information publications are also used in air navigation. Three highly recommended supplementary publications, described below, are *Flight Information Publication Enroute, Flight Information Publication Planning,* and the *Flight Information Publication Terminal.*

FLIP Enroute.—*Flight Information Publications Enroute* (FLIP Enroute) are revised and distributed regularly. They contain almost all of the information about radio aids to navigation for the specific geographical areas they cover. These publications are usually in the form of charts that give all necessary information about airways, radio range stations, VOR and TACAN stations, airports, fan markers, and homing beacons.

FLIP Planning.—Normally found in the flight operations center or other flight planning centers, the *Flight Information Publication Planning* is a loose-leaf notebook of static information used to plan flights. This FLIP Planning contains such pertinent information as special notices, directories of aerodromes, radar and ILS facilities, pilot procedures, mountainous area charts, meteorological data, sunrise/sunset tables, world time charts, and information of further value to pilots.

FLIP Terminal.—The *Flight Information Publication Terminal* has two sections, one for High Altitude and one for Low Altitude. The High Altitude section is carried aboard all military jet aircraft. The Low Altitude section is carried aboard all military reciprocating engine aircraft. The two sections of the FLIP Terminal give information about approach procedures and facilities, minimum altitudes, radio facilities, runway patterns, and other valuable information.

The Federal Government has realized that it is necessary to have a single central organization to control the flight operations of today. Civil and military air travel is now coordinated through the Federal Aviation Administration. The FAA is responsible for the safe and efficient use of the airspace above our Nation. To this end, the Federal Government and its related agencies are pledged.

## CELESTIAL NAVIGATION

Navigators today are aided by the most advanced instruments and techniques. So far in our discussion we have considered the most widely used methods of navigation. Our coverage of the subject, however, would be incomplete without at least a brief examination of celestial navigation.

In many areas, celestial navigation is the only means of navigation on long overwater flights. It is still used on such flights by many military and civilian aircraft.

Celestial navigation is used to determine an aircraft's position when visual, radio, and radar contact with the ground fails or is not available. Because celestial navigation requires a greater knowledge of navigational astronomy, navigation, and mathematics than most of us have at this time, we will not examine this form of navigation as closely as we did the others.

Celestial observations serve several purposes. First, they provide a means of fixing an aircraft's position. Second, celestial observations may serve as direction-finding references to check the accuracy of compass headings and the gyrocompass precession. Third, they are the only reliable means of fixing a position and of direction-finding while in the polar regions.

Navigators frequently employ celestial navigation in isolated areas and over the oceans since it provides an accurate position anywhere in the world. Celestial sightings must be taken with a special instrument, called a sextant, and several calculations must be made. With

precomputation and a periscopic sextant, a navigator can get a reliable fix by celestial observation in about five minutes.

One point which opposes the use of celestial navigation in aircraft is the fact that sightings have to be precise. A pilot of a light plane cannot control the craft and take an accurate instrument reading with his sextant. Hence, pilotage, dead reckoning, and radio-electronic techniques are employed in most air navigation.

### Shooting the Stars

When celestial navigation is used, this, in broad, general terms, is the technique followed. The pilot or navigator selects one of the prominent stars in the sky and observes its altitude above the horizon with a sextant. Then using predetermined celestial navigation tables, he determines from his assumed position the computed altitude of the star and its true bearing. The assumed position is where the navigator assumes himself to be for purposes of taking a "sight" with the sextant. Next, the difference between the altitude of the star as observed with the sextant and the altitude of the star computed from the assumed position indicates how far away the aircraft is from its assumed position. This difference in the observed altitude of the star and its computed altitude is used to plot on a chart a celestial line of position. The aircraft is known to be located somewhere along this line.

The navigator then observes at least two other stars through his sextant and repeats the above procedures. Once he has obtained at least three celestial lines, the intersection of these lines indicates the aircraft's actual position, called a "fix." Other lines of position, such as LORAN, may be combined with celestial lines for a fix.

We have only touched upon this method of navigation, but, as we noted earlier, today's navigators on our most advanced aircraft use far more complicated equipment and rely upon assistance from the ground to a considerable degree. In the next chapter we will continue our examination of the assistance pilots and navigators get from the ground. We will focus our attention primarily on how airborne crews communicate with the ground facilities. We will see how pilots speak to control towers, what the special radio phrases are, and then take an imaginary flight to hear actual flight communications as they happen.

## REVIEW QUESTIONS

1. **List five different types of radio navigation facilities and explain their uses.**
2. **What is one major advantage of radio navigation over all other types of navigation?**
3. **List four radio and electronic aids to navigation and explain what they do.**
4. **Why has VOR equipment replaced the LF/MF radio range?**
5. **Explain two purposes of Automatic Direction Finders.**

## THINGS TO DO

1. Prepare a radio range model such as shown in Figure 30. Use model airplanes to demonstrate how the range is used. If a thin metal backing is used on the board, small planes with a magnet attached will allow you to use the display board in a vertical position so that it can be seen by everyone in the class.
2. Using a tape recorder, make a tape of a typical flight during which the pilot goes through a range problem and correctly identifies his position. Prepare another tape in which the pilot makes a mistake. See if your fellow students can identify where the pilot made his mistake.

## SUGGESTIONS FOR FURTHER READING

CAIDIN, MARTIN. *Let's Go Flying.* New York: E.P. Dutton & Co., 1960.

DOHM, JOHN, ed. *The New Private Pilot.* North Hollywood, Calif.: Pan American Navigation Service, 1962.

Federal Aviation Administration. *Flight Instructor's Handbook, AC–61–16.* Washington, D.C.: U.S. Government Printing Office, current.

Federal Aviation Administration. *Private Pilot's Handbook of Aeronautical Knowledge.* Washington, D.C.: U.S. Government Printing Office, 1965.

LYON, THOBURN C. *Practical Air Navigation.* 10th ed. Denver: Jeppesen & Co., 1966.

U.S. Air Force. *AFM 51–40, Air Navigation.* Vol 1. Washington, D.C.: Department of the Air Force, 1968.

VAN SICKLE, NEIL D., ed. *Modern Airmanship.* Princeton, N.J.: D. Van Nostrand Co., Inc., 1966.

*Chapter* 9

# Radio Procedures

**THIS CHAPTER presents the common phraseology used in radio communications. The radio-communication techniques presented here are those employed by most pilots throughout the world. Also, a sample radio conversation is given to provide a better understanding of radio communication techniques. When you have studied this chapter, you should be able to: (1) explain the procedures involved in using the aircraft radio; and (2) make limited use of the common radio phraseology and explain why such a system is necessary.**

THROUGHOUT this text we have continually mentioned radio procedures and the use of the aircraft radio. At this time, we should take a side trip from air navigation techniques and look at the basic procedures of radio communications.

## THE RADIO LANGUAGE

Many people have the impression that airplane radio communications are extremely complicated. This is not true and we hope to introduce you to the interesting world of radio communications. We will not try to make you proficient in using the radio, but we will attempt to acquaint you with the various procedures.

Before we progress any further, let us dispel any preconceived thoughts you may have about the use of aircraft radios. Radio com-

munications do employ certain words or phrases that have specific meanings. However, there is no foreign language involved and deeper examination will disclose that the words or phrases have precise meanings. Although simple, clearly spoken messages will produce the necessary results, the following list of radiotelephone phrases reduces the length of transmission and provides uniformity.

### PHRASEOLOGY

| *Word or phrase* | *Meaning* |
|---|---|
| ACKNOWLEDGE | Let me know that you have received and understand this message. |
| ROGER | I have received all of your last transmission. (Used to acknowledge receipt, not to be used for any other purpose.) |
| AFFIRMATIVE | Yes. |
| NEGATIVE | That is not correct. No |
| I SAY AGAIN | I repeat. |
| SAY AGAIN | Please repeat. |
| STAND BY | Await further instructions or orders. |
| VERIFY | Check with originator. |
| OVER | My transmission is over and I expect a response from you. |
| OUT | This conversation is ended and I do not expect a response from you. |
| CORRECTION | An error has been made in the transmission. |

To ensure that misunderstanding does not occur in radio communication, a *phonetic alphabet* has been adopted by the nations of the International Civil Aviation Organization.* This alphabet is used when receiving conditions are poor and in all instances when spoken words may be confused or misunderstood.

### RADIO COMMUNICATION PROCEDURES

Two-way radio procedures are very simple to perform. To illustrate this point, we will make an imaginary flight from our local airport at Patrick to the civil airport at Speerton.

First we must go to the Weather Bureau Airport Station and Check the weather. After this, a VFR flight plan is filed with the Patrick Flight Service Station (FSS)** requesting flight following service.

* See Appendix A for phonetic alphabet.
** See page 40 for information about FSS.



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The FSS designates Hinton as our flight watch station. All other preparations are completed and our aircraft is loaded for the flight.

The pre-flight checklist has been completed and it is now time to takeoff. When ready to taxi, we call the control tower on the ground control frequency given in the *Airmen's Information Manual* and give the following information: aircraft identification, type of flight plan (VFR or instrument) and the first point of intended landing.

**Pilot:** GROUND CONTROL, THIS IS CESSNA TWO ONE THREE NINER BRAVO AT HANGAR THREE, READY FOR TAXI, VFR FLIGHT TO SPEERTON. OVER.

**Tower:** THREF NINER BRAVO, CLEAR TO RUNWAY ONE SIX. WIND ONE FOUR FIVE DEGREES AT ONE ZERO. ALTIMETER TWO NINER NINER EIGHT. TIME ONE FOUR THREE ZERO.

**Pilot:** THREE NINER BRAVO, ROGER.

The tower gave us a clearance to proceed to our takeoff runway. Then we were given the direction and speed of the wind, followed by the altimeter setting for Patrick and the time. We then acknowledged the information.

After taxiing to the required position and completing our final checklist, we change our radio transmitter and receiver to the appropriate tower frequency and call the tower.

**Pilot:** PATRICK TOWER CESSNA TWO ONE THREE NINER BRAVO, READY FOR TAKEOFF.

The controller determines that there is no conflicting traffic and replies to us:

**Tower:** THREE NINER BRAVO, CLEARED FOR TAKEOFF.

**Pilot:** CESSNA TWO ONE THREE NINER BRAVO, ROGER.

We remain guarding the control tower frequency until we leave the airport traffic area. We then retune our VHF radio to the appropriate Patrick frequency and call Patrick radio. We give Patrick radio our time of takeoff so that our flight plan can be activated.

**Pilot:** PATRICK RADIO THIS IS CESSNA TWO ONE THREE NINER BRAVO, OFF AT ONE FOUR FIVE ZERO, VFR FLIGHT TO SPEERTON. OVER.

**Station:** Acknowledges transmission.

While in flight, we continue to monitor Patrick radio until we come into the range of our flight watch station at Hinton. Once within the range of Hinton radio, we tune to Hinton radio to give a position report. We first establish contact and then indicate the frequency on which we desire a reply.

Pilot: HINTON RADIO THIS IS CESSNA TWO ONE THREE NINER BRAVO. REPLY ON VOR FREQUENCY. OVER.

Station: CESSNA TWO ONE THREE NINER BRAVO. THIS IS HINTON RADIO. OVER.

We proceed with our message, giving position, time, flight altitude, and VFR flight plan from a point of departure to destination.

Pilot: CESSNA TWO ONE THREE NINER BRAVO TEN MILES EAST OF HINTON ONE EIGHT AT SEVEN THOUSAND FIVE HUNDRED ON VFR FLIGHT PLAN PATRICK TO SPEERTON. OVER.

Station: Acknowledges information and gives us the latest weather data and any other information pertinent to our flight.

Pilot: THREE NINER BRAVO, ROGER. OUT.

We continue our flight until we are approximately 25 miles from Speerton. We then call Speerton approach control on the frequency listed for Speerton in the remarks section of the *Airmen's Information Manual.*

Pilot: SPEERTON APPROACH CONTROL THIS IS CESSNA TWO ONE THREE NINER BRAVO TWO FIVE MILES EAST AT FOUR THOUSAND. LANDING AT SPEERTON. OVER.

As we move closer to the field, we call the control tower and request further information and instructions for landing. The control will give us runway and wind information, and notify us of other traffic at the field.

Pilot: SPEERTON TOWER THIS IS CESSNA TWO ONE THREE NINER BRAVO, FIVE MILES EAST. REQUEST LANDING INSTRUCTIONS. OVER.

Tower: CESSNA TWO ONE THREE NINER BRAVO. FIVE MILES EAST. CLEARED TO ENTER TRAFFIC PATTERN, RUNWAY TWO FOUR, WIND TWO SIX ZERO DEGREES AT ONE ZERO. OVER.

Pilot: CESSNA TWO ONE THREE NINER BRAVO. ROGER.

After entering the traffic pattern on the downwind leg, we report to the tower while turning on the base leg.* We receive and acknowledge a clearance to land and proceed with our landing.

The tower instructs us to tune to ground control frequency while we are turning off the active runway. We change our receiver and transmitter to the ground control frequency and wait for taxiing instructions. We acknowledge all instructions and proceed as directed, guarding the ground control frequency until the aircraft has been parked. The last thing we do is to notify the Flight Service Station that we have landed at our destination. The FSS will then close our flight plan from Patrick.

We have seen how standard radio communications are made. In other than normal conditions, radio communications also serve as important links with the ground.

In the event a pilot becomes lost, the Federal Aviation Administration has established basic flight rules that should aid in determining position. While a pilot is lost or is experiencing other types of emergencies, his primary contact with ground facilities is the radio. A pilot in an emergency situation should remember that ground personnel are waiting to be of assistance.

## REVIEW QUESTIONS

1. **Why has the International Civil Aviation Organization adopted a phonetic alphabet?**
2. **What is the purpose of having a common set of words and phrases for use in aircraft radio communication?**
3. **What is one of the first actions a pilot should take when experiencing difficulty in flight?**

## THINGS TO DO

1. Using an aeronautical chart available to all students, prepare a written script or a recorded tape of radio communications for a local flight. After you have given a couple of position reports so that the other students think they know the direction of your flight, let a volunteer assume the role of the pilot and without your script have him make the next position report. If you vary the direction of your flight in your script or tape, some interesting developments can be worked into this exercise.

* For illustration of traffic pattern, see Appendix B.

2. Plan a flight that will cross several position reporting stations and rehearse the radio communications required using one of your classmates as the ground station controller. Arrange with your instructor to carry out this "flight" in class and let your fellow classmates criticize your technique.

## SUGGESTIONS FOR FURTHER READING

CAIDIN, MARTIN. *Let's Go Flying*. New York: E. P. Dutton & Co., 1960.

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TOWER, MERRILL E. *Basic Aeronautics*. Fallbrook, Calif.: Aero Publishers, Inc., 1952.

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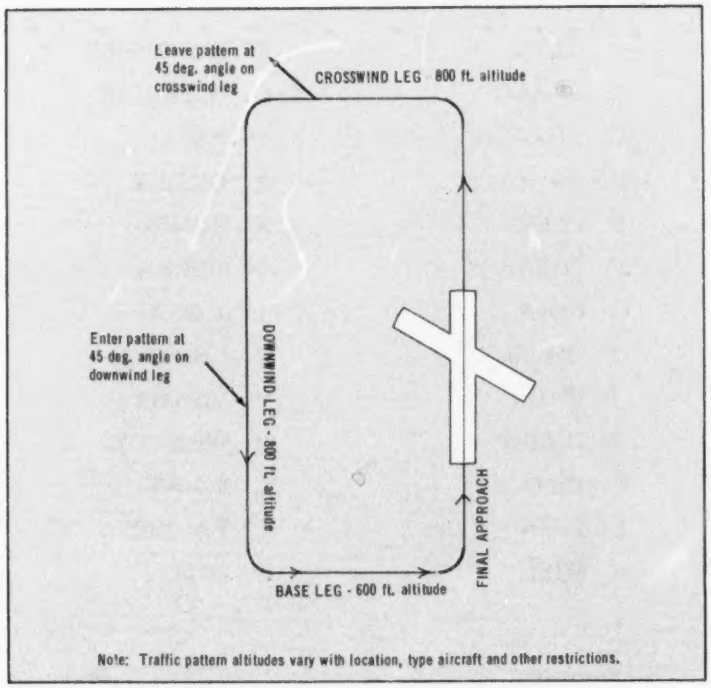
*Appendix A*

## International Phonetic Alphabet

| | |
|---|---|
| A ALFA | N NOVEMBER |
| B BRAVO | O OSCAR |
| C CHARLIE | P PAPA |
| D DELTA | Q QUEBEC |
| E ECHO | R ROMEO |
| F FOXTROT | S SIERRA |
| G GOLF | T TANGO |
| H HOTEL | U UNIFORM |
| I INDIA | V VICTOR |
| J JULIET | W WHISKEY |
| K KILO | X X RAY |
| L LIMA | Y YANKEE |
| M MIKE | Z ZULU |

*Appendix B*

## Traffic Pattern


Leave pattern at 45 deg. angle on crosswind leg
CROSSWIND LEG - 800 ft. altitude
Enter pattern at 45 deg. angle on downwind leg
DOWNWIND LEG - 800 ft. altitude
FINAL APPROACH
BASE LEG - 600 ft. altitude
Note: Traffic pattern altitudes vary with location, type aircraft and other restrictions.

DOWNWIND LEG — That portion of traffic pattern parallel to, but in the opposite direction to, the landing.

BASE LEG — That portion of the traffic pattern at a right angle to the landing direction on the *downwind* side of airport.

FINAL APPROACH — That portion of the traffic pattern from the last turn into the landing direction until runway contact is made.

CROSSWIND LEG — That portion of the traffic pattern at a right angle to the landing direction on the *upwind* side of airport.

## *Appendix C*

# Common Abbreviations

| | |
|---|---|
| AAS | airport advisory service |
| AC | approach control tower |
| ADF | automatic radio direction finder |
| AGL | above ground level |
| AIM | Airman's Information Manual |
| ALS | automatic landing system |
| ARTCC | air route traffic control center |
| AS | airspeed |
| ASDE | airport surface detection equipment (radar) |
| ATA | actual time of arrival |
| ATC | air traffic control |
| BS | broadcasting station (commercial) |
| CAS | calibrated airspeed |
| CC | compass course |
| CH | compass heading |
| CDI | course deviation indicator |
| Ck.pt. | check point |
| CLDI | course line deviation indicator |
| COP | change over point (as between VORs) |
| Corr | correction |
| Cr | cruising |
| D | drift angle |
| DCA | drift correction angle |
| Dev | deviation (compass) |
| DF | direction finder |
| DG | directional gyro |
| DME | distance measuring equipment |
| DR | dead reckoning |
| DVFR | defense visual flight rules |
| EAS | equivalent airspeed |
| EAT | expected approach time |
| ETD | estimated time of departure |
| ETE | estimated time enroute |
| FAR | Federal Aviation Regulations |
| FHA | fuel hours available |
| FL | flight level in hundreds of feet |
| FPDI | flight path deviation indicator |
| FSS | flight service station |
| Ft/min | feet per minute |
| GCA | ground controlled approach |
| GMT | Greenwich mean time |
| GP | glide path |
| GS | ground speed |
| H-SAB | H beacon with automatic weather broadcast |
| IAS | indicated airspeed |
| ICAO | International Civil Aviation Organization |
| IFF | identification friend or foe |
| IFR | instrument flight rules |
| ILS | instrument landing system |
| INT | intersection |
| km | kilometer |
| kt | knot (nautical mile) |
| Lat | latitude |
| LMM | compass locator at middle marker of ILS |
| Lo | longitude |
| LOM | compass locator at outer marker of ILS |
| LOP | line of position |
| L-R | left-right needle of VOR receiver |
| LRR | long range radar |
| MAA | maximum authorized altitude (IFR) |
| MC | magnetic course |

| | |
|---|---|
| MCA | minimum crossing altitude |
| MDF | manually operated radio direction finder |
| MEA | minimum enroute altitude |
| MH | H radiobeacon, less than 50 watts power |
| MH | magnetic heading |
| MOCA | minimum obstruction clearance alt. |
| mph | miles per hour |
| MSL | mean sea level |
| MTI | moving target indicator (radar) |
| nt.mi. | nautical mile |
| OBS | omnibearing selector |
| OM | outer marker of ILS |
| PAR | precision approach radar |
| RBN | radiobeacon (non-directional) |
| R/C | rate of climb |
| R/D | rate of descent |
| REIL | runway end identifier lights |
| RM | relative movement |
| RVR | runway visibility range |
| R/W | runway |
| SAR | search and rescue |
| SFL | sequenced flashing lights |
| SID | standard instrument departure |
| st.mi. | statute mile |
| T | total time, same as FHA |
| TAS | true airspeed |
| TC | true course |
| TH | true heading |
| TR | track |
| TVOR | low powered terminal VOR |
| TWEB | transcribed weather broadcast |
| UHF | ultra high frequency |
| Var | variation (magnetic) |
| VFR | visual flight rules |
| VHF | very high frequency |
| VOR | omnidirectional radio range |
| W | wind |
| WCA | wind correction angle |
| Z | bearing, from true north |
| Z | Greenwich mean time |

# Glossary

## A

**accelerometer**—an instrument that measures and indicates the magnitude of accelerations of an aircraft in flight

**agonic line**—an imaginary line over the earth that joins all points along which there is no magnetic variation

**aileron**—a hinged or movable portion of the trailing edge of an airplane wing used to control the motion of the airplane about its longitudinal axis

**airport**—a tract of land or water reserved for the landing and takeoff of aircraft, also provides shelter, supplies, and repair

**airspeed**—the speed of an aircraft relative to the air through which it is moving

**airway**—an air route along which navigational aids are maintained

**altimeter**—an aneroid instrument for measuring height of an aircraft above sea level or above an airport of departure or destination

**altitude**—vertical distance from a given level to an aircraft in flight
(absolute)—height of aircraft above the earth
(corrected)—actual height of aircraft above sea level

**anemometer**—an instrument for measuring the speed of wind

**atmosphere**—the whole mass of air surrounding the earth

**attitude**—position of an aircraft determined by the inclination of its axes to some reference, usually the earth or the horizon

**autogiro**—type of rotor plane in which lift is created by revolving blades hinged to a vertical shaft above the fuselage, different from helicopter because some forward speed is required for takeoff, forward movement produced by engine fitted with conventional prop

**axes of an aircraft**—three fixed lines of reference perpendicular to each other and passing through the center of gravity of the plane: 1. longitudinal, from nose to tail; 2. lateral, parallel to a line drawn from wing tip to wing tip; 3. vertical, perpendicular to the other two

## B

**bank**—to incline an airplane laterally or roll it about its longitudinal axis; the position of an aircraft when its lateral axis is inclined to the horizontal

**barometer**—instrument which indicates atmospheric pressure



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**beam**—narrow directional radio signal formed by joining the A and N signals of a radio range station

**bearing**—angle from one object to another, measured clockwise through 360° from a given reference

## C

**ceiling**—height above ground of the base of a cloud formation

**centrifugal force**—force which tends to force an object away from the center of rotation

**centripetal force**—force which tends to force an object inward toward a center of rotation

**chart**—aeronautical map showing lines of latitude and longitude, compass roses, topographical and aeronautical information, and other aids and dangers to air navigation

**check list**—list of items requiring pilot's attention for various flight operations

**check point**—known or designated point, such as a landmark, beacon, city, used as a reference in air navigation and in flying

**climb**—action of airplane when ascending under power

**compass**—instrument which determines direction

**compass rose**—a graduated circle, usually marked in degrees, indicating directions and printed or inscribed on a compass card or elsewhere as upon an aeronautical chart

**contact flying**—flight by visual reference to the ground

**contour line**—line connecting all points of the same elevation above sea level

**coordinates**—Any of two or more magnitudes that determine position

**course**—direction over surface of earth that an aircraft is intended to travel

## D

**degree**—a 360th part of a circumference of a circle

**deviation**—angular distance between magnetic heading and compass heading of airplane, caused by magnetic attraction

**deviation card**—card placed near a compass giving deviation correction for converting magnetic headings to compass headings

**deviation error**—error as a magnetic compass caused by the magnetic influences in the structure and equipment of an aircraft

**dive**—steep descent, with or without power

**doppler effect**—the apparent shift in frequency of transmitted energy as the distance between transmitter and receiver decreases or increases

**drift angle**—horizontal angle between long axis of aircraft and its path relative to ground

## E

**equi-signal zone**—zone of equal signal strength of the "on course" signal of a radio range, steady tone is heard

**estimated time of arrival (ETA)**—estimated time at which pilot expects to arrive at his destination as based on calculations of known factors

## F

**fix**—a definite geographic position of an aircraft determined by the intersection of two or more bearings or lines of position

## G

**geocentric**—relating to or measured from the center of the earth; having the earth as center

**geographic poles**—north and south poles through which all geographic meridians pass and around which the earth rotates

**gnomonic**—method of chart projection on which straight lines represent great circle courses

**graticule**—a system of vertical and horizontal lines used to divide a drawing, picture, chart, etc., into smaller sections. On a map the graticule consists of the latitude and longitude lines

**great circle**—imaginary circle on the earth's surface made by passing a plane through the earth's center

**Greenwich meridian**—meridian passing through Greenwich, England from which longitude is measured

**ground speed**—actual speed of the airplane over the ground

## H

**heading**—(compass)—angle between north as indicated by airplane compass and direction in which ship is headed

(magnetic)—angle between magnetic north and direction in which ship is pointed

(true)—angle between true north and direction in which airplane is pointed

**homing**—process of flying toward a transmitting station by means of loop antenna or RDF

## I

**instrument flight**—flight controlled solely by reference to instruments, using dead reckoning and radio navigation

**interrogator**—an electronic device for transmitting challenging or interrogating pulses for reception and response by a transponder.

**isogonic lines**—imaginary lines on surface of earth at all points on which magnetic variation is the same

## J

## K

**knot**—measure of speed used in navigation, 6076.1 ft

## L

**Lambert projection**—method of projecting a portion of earth onto a flat chart with minimum amount of distortion

**landing**—act of terminating flight, descending, contacting land or water and coming to halt

**latitude**—angular measurement north and south of equator of any point on the earth, measured in degrees, minutes, and seconds

**level-off**—make flight path of airplane horizontal after climb or dive

**lift**—vertical reaction to passing airfoil through the air

**log**—written record of observed or computed navigational data

**longitude**—angular measurement of any point on earth's surface east or west of Prime Meridian, measured in degrees, minutes, and seconds

## M

**magnetic north**—north of the earth's magnetic field, situated at about Lat 71° N, Long 96° W, more than 1000 miles from geographic pole

**map**—flat surface representation of portion of earth's surface drawn to scale

**Mercator**—chart projection upon which lat. and long. are represented as straight lines intersecting at right angles, rhumb lines are straight lines and great circles are curved lines

**meridian**—great circle on earth's surface passing through N&S poles

**mid-meridian**—meridian passing through the halfway point between two places on the earth's surface

**mile** (nautical)—6076.1 feet, (statute)—5280 feet

**mph**—standard abbreviation for miles per hour

## N

**nautical mile**—a measure of distance equal to approximately 6,080 feet.

## O

## P

**parallel (of latitude)**—circle of earth's surface parallel to Equator at all points

**pilotage**—method of conducting an aircraft from one point to another by observation of landmarks

**plot**—accurately marking position and/or course of aircraft on navigational chart

**Prime Meridian**—meridian from which longitude is measured, commonly the Greenwich meridian

**projection**—any of several methods of representing the surface of the earth upon a flat surface

**protractor**—instrument for laying and measuring angles on paper

## Q

**quadrant**—one of four signal zones which are 90° apart, identified by either the "N" or "A" signal surrounding a radio range station

## R

**radio compass**—radio receiver using a fixed or rotating loop antenna and a visual indicator, used for "homing" of a flight directly toward or away from a radio station

**radio direction finder (RDF)**—radio receiver using manually operated loop antenna to determine direction to or from transmitting station

**radio navigation**—method of conducting aircraft from one point to another by radio aids to navigation

**rhumb line**—line on a chart or surface of the earth that cuts all meridians at constant angles

## S

**sextant**—instrument used in celestial navigation for determining altitude or angle of celestial body above the horizon

**sideslip**—motion of aircraft in direction downward and parallel to an inclined lateral axis

**skid**—sliding sideways away from the center of curvature when turning, caused by excessive rudder control

**speed (air)**—speed of aircraft through the air

## T

**tachometer**—instrument that measures in rpms the rate at which an engine crankshaft turns

**takeoff**—handling of plane leading up to and into the instant of leaving the ground

**taxi**—to operate an airplane under own power, either on land or water, other than in actual takeoff or landing

**track**—actual path over ground of aircraft in flight

**transponder**—an electronic device that receives a challenging signal and automatically transmits a response

**triangulation**—a method of finding a location by means of taking bearings with reference to two fixed points a known distance apart, thus obtaining the values of one side and all the angles of a triangle, from which the position can be computed

**turbulence**—irregular motion of atmosphere produced by: (1) air flowing over uneven surface; (2) two currents of air flowing past each other at different speeds or different directions

**turn indicator**—instrument that indicates the direction and rate of turn of an aircraft

## U

## V

**variation**—angle at any given point between the true meridian and a line drawn to the magnetic North Pole, labeled East or West, depending on which side of the true meridian the North Pole lies

**vector**—an entity which has both magnitude and direction, such as a force or velocity.

**visibility**—the greatest distance toward the horizon at which prominent features can be seen and recognized

**Visual Omni Range (VOR)**—type of ground-based radio aid used in navigation

## W

**wind**—moving air

## X

## Y

**yaw**—angular motion to right or left about the vertical axis of an airplane

## Z

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